


RESEARCH NOTE

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# Physicochemical quality of water and health risks associated with consumption of African lung fish (*Protopterus annectens*) from Nyabarongo and Nyabugogo rivers, Rwanda

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## Abstract

**Objective:** To determine the quality of water, heavy metal content of edible muscles of a piscivorous fish (*Protopterus annectens*) and assess the health risks associated with using water and consumption of *P. annectens* from Nyabarongo and Nyabugogo rivers of Rwanda.

**Results:** All the water quality parameters were within World Health Organization's acceptable limits except total nitrogen, iron, manganese and lead levels. Edible muscles of *Protopterus annectens* contained  $272.8 \pm 0.36$ ,  $292.2 \pm 0.25$ ,  $8.8 \pm 0.36$ ,  $135.2 \pm 0.15$ ,  $148.0 \pm 0.21$  and  $432.0 \pm 0.50$  mg/kg of iron, manganese, copper, zinc, chromium and lead at Ruliba station and  $336.0 \pm 0.70$ ,  $302.6 \pm 1.22$ ,  $6.4 \pm 0.26$ ,  $44.7 \pm 0.20$ ,  $138.2 \pm 0.17$  and  $302.4 \pm 1.50$  mg/kg of iron, manganese, copper, zinc, chromium and lead at Kirinda bridge of Nyabarongo river. Health risk assessments indicated that though ingestion and dermal contact with heavy metals in water from the rivers may not cause obvious health effects, consumption of *Protopterus annectens* from Nyabarongo river may lead to deleterious health effects.

**Keywords:** Cancer risk, Estimated daily intake, Heavy metals, Target hazard quotient

## Introduction

Environmental studies in Rwanda have reported that rivers: Mpazi, Nyabarongo, Rusine and Nyabugogo are being continuously polluted by anthropomorphic contributions [1]. Nyabugogo river pour its water into Lake Victoria and the pollution of this lake is now rated among the top ten worldwide [2]. The increasing load

of contaminants has greatly deteriorated the quality of water and fish caught in Lake Victoria [3]. The presence of toxic heavy metals in water and fish poses health risks such as development of cancer, renal failure, liver damage, cardiovascular diseases and eventually death [4].

As a contribution to environmental monitoring and public health, the current study investigated the physicochemical profile of water, heavy metal content of *Protopterus annectens* and estimated the health risks associated with use of water and consumption of *P. annectens* from Nyabarongo and Nyabugogo rivers. The results were compared with reports from previous studies.

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**Main text**

**Method**

The current study was done in Nyabarongo and Nyabugogo rivers of Rwanda. The apparatus were those previously used [5, 6]. Study approval was granted by Department of Chemistry, College of Science and Technology, University of Rwanda (Approval No. 213000076).

**Sampling and analysis**

Samples were taken from Ruliba station in Kigali (1° 58' 37" S and 30° 0' 50" E) and Kirinda bridge in Karongi district (204° 4" S and 290° 20' 46" E) on Nyabarongo river. On Nyabugogo river, samples were taken from Giticyinyoni (10° 55' 22" S and 300° 2' 52" E). Water samples (n=1 for each site) were obtained in triplicate between April 2019 and May 2019 (10:00 to 11: 00 am, Central African Time) as described by Omara et al. [5]. Fish (6.2 to 8.1 cm; 700–903 g) were caught in triplicate from Nyabarongo river (n=3 for each site), identified and prepared for analysis as described before [7].

Temperature, pH and electrical conductivity of water samples were determined on-site [6]. Total, ammoniacal, nitrite and nitrate nitrogen, sulphate and phosphate contents of water samples were determined following APHA method [8]. Iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), chromium (Cr), cadmium and lead (Pb) in water samples were quantified using HACH DR/2500 spectrophotometer. Fish samples were analyzed for heavy metals using a Varian AA240 atomic absorption spectrometer and results in mg/L were converted to mg/kg [7].

Quality control was performed with spiked samples analyzed once for every 10 fish samples. Recovery percentages ranged from 97.6 to 102.5%. Blanks were determined throughout the analyses and used to correct concentrations obtained. Samples were analyzed in triplicate.

**Human health risk assessment**

Average daily doses (mg/L/day) were calculated for adults (as the general population) and children (as a sensitive group) to estimate human exposure through direct ingestion (ADD<sub>ing</sub>) and dermal contact (ADD<sub>derm</sub>) with water (Eqs. 1, 2). Estimated daily intake (EDI, mg/kg/day) for fish was calculated as described elsewhere (Eq. 3) [5, 7, 9].

$$ADD_{ing} = \frac{C_{hm} \times W_{ir} \times E_d \times E_f}{W_{ab} \times T_{aet}} \tag{1}$$

$$ADD_{derm} = \frac{C_{hm} \times S_A \times AF \times E_d \times E_f}{W_{ab} \times T_{aet}} \tag{2}$$

$$EDI = \frac{E_f \times E_d \times F_{ir} \times C_f \times C_{hm}}{W_{ab} \times T_{aet}} \tag{3}$$

where  $C_{hm}$ =metal concentration in water or fish,  $S_A$  is exposed area=4350 and 2800 cm<sup>2</sup> for adults and children [9],  $W_{ir}$  is water ingestion rate=21.0 and 1.8 L/day for adults and children [10],  $E_d$  is the exposure duration=67 years [11],  $E_f$  is the exposure frequency=365 days/year, AF is skin adherence factor=0.7 and 0.2 mg/cm<sup>2</sup>/day for adults and children,  $F_{ir}$  is fresh fish ingestion=48 g/person/day,  $C_f$  is conversion factor for fresh to dry weight for fish=0.208,  $W_{ab}$  is average body weight=15 kg and 60 kg for children and adults,  $T_{aet}$  is the average exposure time= $E_d \times E_f$  [5, 12].

Health risk index, the total risk of a non-carcinogenic element was evaluated using target hazard quotient (THQ) (Eq. 4) [5, 7, 13].

$$THQ = \frac{ADD}{R_f D} \text{ or } THQ = \frac{EDI}{R_f D} \tag{4}$$

where  $R_f D$  is the reference dose. Since exposure to two or more toxicants results in additive and/or interactive effects, the total THQ was treated as the sum of the individual metal THQs. Carcinogenic risk, which is the product of  $ADD_{ing}$ ,  $ADD_{derm}$  or EDI and the ingestion cancer slope factor was calculated for Cr, Cd and Pb.

**Statistical analysis**

Analytical data were presented as means ± standard deviations. One way ANOVA was done followed by Tukey test ( $p < 0.05$ ) using Sigma plot software (v14, Systat software Inc., USA).

**Results**

Results of water and fish analyses are given in Tables 1 and 2. Toxicity indices used for risk assessments are given in Table 3, Additional files 1, 2, 3 Tables S1, S2 and S3.

**Discussion**

**Water quality**

Nearly all the water quality parameters were within WHO permissible limits [14]. Temperatures were normal while the pH of samples were slightly alkaline, comparable to 7.8 reported by Usanzineza et al. [21] in Lake Muhazi. Nhapi et al. [1] reported a pH of  $7.24 \pm 0.18$  at Rwesero, the point after which Nyabugogo river flows out of Lake Muhazi. Alkaline pH in Rwandese rivers were reported to be due to alkaline wastes from UTEXRWA industry in Kigali [22]. Overall, the pH values recorded were within WHO limits [14]. It should be noted that even within acceptable pH ranges, slightly high pH

**Table 1 Hydrochemical properties of water from Nyabarongo and Nyabugogo rivers, Rwanda**

Parameter	Nyabarongo river		Nyabugogo river	WHO guidelines [14]
	Ruliba station	Kirinda bridge	Giticyinyoni	
Temperature (°C)	22.6 ± 0.30	23.0 ± 0.26	22.5 ± 0.40	25.0
pH	8.15 ± 0.07	7.96 ± 0.06	8.22 ± 0.03	6.5–8.5
Conductivity (µ/Scm)	74.3 ± 3.84	20.0 ± 0.15	102.0 ± 1.0	1000
TDS (mg/L)	39.0 ± 2.0	10.0 ± 0.01	52.9 ± 0.36	2000
Total nitrogen (mg/L)	1.62 ± 0.02	1.56 ± 0.001	<i>12.81 ± 9.51</i>	3.0
Nitrite nitrogen (mg/L)	0.01 ± 0.00	0.017 ± 0.02	0.014 ± 0.003	0.1
Nitrate nitrogen (mg/L)	0.40 ± 0.01	1.39 ± 0.01	1.07 ± 0.058	10
Ammoniacal nitrogen (mg/L)	0.153 ± 0.015	0.117 ± 0.01	0.12 ± 0.006	0.5
Sulphates (mg/L)	0.58 ± 0.017	0.270 ± 0.02	0.86 ± 0.03	1000
Phosphates (mg/L)	0.42 ± 0.01	0.21 ± 0.02	0.39 ± 0.058	5.0
Fe (mg/L)	<i>1.61 ± 0.03</i>	<i>0.63 ± 0.02</i>	<i>1.57 ± 0.02</i>	0.3
Mn (mg/L)	<i>0.53 ± 0.002</i>	0.02 ± 0.002	<i>0.49 ± 0.03</i>	0.1
Cu (mg/L)	0.24 ± 0.02	BDL	0.29 ± 0.058	0.5
Zn (mg/L)	BDL	0.09 ± 0.01	0.43 ± 0.058	3.0
Cr (mg/L)	BDL	<i>0.06 ± 0.002</i>	<i>0.15 ± 0.00</i>	0.05
Cd (mg/L)	0.106 ± 0.002	BDL	BDL	0.01
Pb (mg/L)	<i>0.051 ± 0.01</i>	<i>0.75 ± 0.02</i>	<i>0.59 ± 0.058</i>	0.01

BDL below method detection limit

Values in italics indicate exceedance of WHO limits

**Table 2 Heavy metal concentrations in *P. annectens* from Nyabarongo river in comparison with other global studies**

Study area	Mean heavy metal concentration (mg/kg)							Year	Authors
	Fe	Mn	Cu	Zn	Cr	Cd	Pb		
Nyabarongo river, Rwanda <sup>a</sup>	<i>272.8 ± 0.36</i> <i>(336.0 ± 0.70)</i>	<i>292.2 ± 0.25</i> <i>(302.6 ± 1.22)</i>	8.8 ± 0.36 <i>(6.4 ± 0.26)</i>	<i>135.2 ± 0.15</i> <i>(44.7 ± 0.20)</i>	<i>148.0 ± 0.21</i> <i>(138.2 ± 0.17)</i>	BDL (BDL)	<i>432.0 ± 0.50</i> <i>(302.4 ± 1.50)</i>	2020	This study
Lower River Benue, Nigeria	0.36 ± 0.02	ND	ND	ND	ND	ND	0.09 ± 0.01	2018	[15]
Oguta Lake, Nigeria	ND	ND	<i>30.10</i>	ND	3.75	0.41	<i>18.10</i>	2016	[16]
Nkisa river, Nigeria	<i>174.66</i>	<i>11.81</i>	4.92	<i>211.33</i>	1.03	<i>0.79</i>	<i>0.98</i>	2014	[17]
Benin city, Nigeria.	ND	ND	ND	ND	ND	0.32 <sup>F</sup> , 0.52 <sup>D</sup>	ND	2011	[18]
Anambra river, Nigeria	<i>60.23 ± 0.37<sup>b</sup></i> <i>54.60 ± 0.20<sup>c</sup></i>	0.94 ± 0.06 <i>1.00 ± 0.01</i>	3.01 ± 0.40 2.86 ± 0.31	10.60 ± 0.08 11.40 ± 0.30	0.16 ± 0.03 0.17 ± 0.02	ND ND	0.01 ± 0.02 0.01 ± 0.02	2009	[19]
FAO/WHO limit	30.0	1.0	30.0	40.0	10.0	0.5	0.5		[20]

Detection limits calculated with reagent blanks were 1.50, 0.20, 0.60, 2.50, 0.50, 1.14, 1.20 and 0.37 mg/kg for Fe, Mn, Cu, Zn, Cr, Cd and Pb, respectively. Values in italics are higher than their corresponding heavy metal permissible limits in fish

ND not determined, F fresh sample, D dry sample, BDL below method detection limit

<sup>a</sup> Results in parentheses are for *P. annectens* from Kirinda bridge; <sup>b, c</sup> results in these rows were obtained in wet and dry seasons respectively

causes water to have a slippery feel whereas slightly low pH may cause water to have a bitter or metallic taste [6].

Conductivity and total dissolved solids recorded were lower than those previously reported for water from Nyabugogo marshland, Nyabugogo, Rwanzekuma and Ruganwa rivers [21]. High total dissolved solids affect the

aesthetic quality of water, interferes with washing operations and can be corrosive to plumbing fixtures. Total Kjeldahl nitrogen were also low; only water from Giticyinyoni had total nitrogen higher than the maximum acceptable limit. Similarly, nitrite, nitrate and ammoniacal nitrogen levels were low. Insignificant differences in

**Table 3** Estimated daily doses through dermal contact and ingestion of water and consumption of *P. annectens*

Indices	Group	Sampling point	Fe	Mn	Cu	Zn	Cr	Cd	Pb	
ADD <sub>ing</sub> (mg/L/day)	Adults	Ruliba station	3.64E-07	1.86E-07	8.40E-08	NA	NA	3.71E-08	1.79E-08	
		Kirinda bridge	2.21E-07	7.00E-09	NA	3.15E-08	2.10E-08	NA	2.63E-07	
		Giticyinyoni	5.50E-07	1.72E-07	1.02E-07	1.51E-07	5.25E-08	NA	2.07E-07	
	Children	Ruliba station	1.93E-07	6.36E-08	2.88E-08	NA	NA	1.27E-08	6.12E-09	
		Kirinda bridge	7.56E-08	2.40E-09	NA	1.08E-08	7.2E-09	NA	9.00E-08	
		Giticyinyoni	1.88E-07	5.88E-08	3.48E-08	5.16E-08	1.8E-08	NA	7.08E-08	
ADD <sub>derm</sub> (mg/L/day)	Adults	Ruliba station	8.17E-05	2.69E-05	1.23E-05	NA	NA	5.38E-06	2.59E-06	
		Kirinda bridge	3.20E-04	1.02E-06	NA	4.57E-06	3.05E-06	NA	3.81E-05	
		Giticyinyoni	7.97E-05	2.49E-05	1.47E-05	2.18E-05	7.61E-06	NA	3.0E-05	
	Children	Ruliba station	6.01E-05	1.98E-05	8.94E-06	NA	NA	3.96E-06	1.87E-06	
		Kirinda bridge	2.35E-05	7.46E-07	NA	3.36E-06	2.24E-06	NA	2.80E-05	
		Giticyinyoni	5.86E-05	1.83E-05	1.08E-05	1.61E-05	5.60E-05	NA	2.20E-05	
EDI (mg/kg/day)	Adults	Ruliba station	4.54E-01	<i>4.86E-01</i>	1.50E-02	2.25E-01	2.46E-01	NA	<i>7.19E-01</i>	
		Kirinda bridge	5.59E-01	<i>5.04E-01</i>	1.10E-02	7.4E-02	2.30E-01	NA	<i>5.03E-01</i>	
		Children	Ruliba station	<i>1.816E0</i>	<i>1.945E0</i>	<i>5.90E-02</i>	9.00E-01	9.85E-01	NA	<i>2.88E0</i>
	Children	Kirinda bridge	<i>2.236E0</i>	<i>2.014E0</i>	<i>4.30E-02</i>	2.98E-01	9.20E-01	NA	<i>2.01E0</i>	
		Dermal reference dose (mg/L/day) [12]		1.4E2	9.6E-01	1.2E-02	6.0E-02	6.0E-05	6.0E-05	5.25E-04
		Oral reference dose (mg/kg/day) [11]		7.0E-01	3.0E-01	4.0E-02	3.0E-01	1.5E0	1.0E-03	1.4E-01

NA not applicable

Values in italics are higher than the reference doses of the heavy metals

nitrite levels in water from Nyabugogo river stretch have been reported previously [1]. Presence of nitrites indicate oxidation which is influenced by environmental factors such as re-aeration, photosynthesis and presence of ammonium. Nitrate levels on the other hand were lower than those previously reported for Nyabugogo river [1]. Overall, total nitrogen in levels above acceptable limits in water may lead to low levels of dissolved oxygen affecting aquatic organisms. Thus, there is no potential contamination of water from sewage discharges and agronomic activities at the studied stations of Nyabarongo and Nyabugogo rivers.

High phosphate levels in a river indicates pollution from sewage discharges or agricultural activities [6]. In this study, low levels of phosphates and sulphates were recorded, corroborating a previous report [1] which speculated that high levels of sulphates in some sites of Nyabugogo river could be due to pollution by wastes from UTEXRWA factory.

For heavy metals, Fe, Mn and Pb were in concentrations higher than WHO limits. The high levels of Fe recorded agreed with Usanzineza et al. [21] who reported  $0.756 \pm 0.734$  mg/L of Fe in Lake Muhazi. Nhapi et al. [1] speculated that high Fe levels in this area could be due to geological composition of its red soils and this is supported by a study [23] which reported 2896 mg/kg of Fe in soils from Nyabugogo downstream. For Pb, Nhapi et al. [1] hinted that the high levels could be due to

alkaline chemicals from Nyabugogo tannery. Occurrence of Pb in the rivers could also be due to use of leaded petrol and dumping of dead lead accumulators into rivers [7]. Lead is a toxic non-essential metal that interferes with essential trace metals such as calcium and Zn. High Mn levels recorded in this study is corroborated by a preceding study which recorded  $28.85 \pm 23.53$  mg/L of Mn in Nyabarongo stream [1]. Thus, the high Mn levels could be due to the surrounding geological formation and disturbance of soils which causes discharge of manganese-rich runoffs [1].

**Heavy metal content of *P. annectens* muscles**

Fish is migratory but heavy metal accumulation in fish is an evidence of exposure to a polluted aquatic environment. High levels of heavy metals were recorded in muscles of *P. annectens* and the chemical sequence followed was Pb > Mn > Fe > Cr > Zn > Cu > Cd at Ruliba station and Fe > Mn > Pb > Cr > Zn > Cu > Cd at Kirinda bridge (Table 2). All metal concentrations recorded except that of Cu and Cd were above FAO/WHO limits. Fish ingest heavy metals by direct uptake from water or by absorption through its organs [5, 7]. Chronic intake however depends on both external and inherent factors. Thus, the high levels of heavy metals recorded in *P. annectens* in this study could be because it is a piscivorous species [5]. The metal levels reported in *P. annectens* were higher than those previously reported except [17]

which reported a concentration of 211.33 mg/kg for Zn (Table 2). Overall, differences in metal concentrations in *P. annectens* could be attributed to differences in the heavy metal concentrations of water in the studied parts of Nyabarongo river.

#### Human health risk assessment

In this study, the estimated average daily doses through ingestion and dermal contact with contaminated water ranged from  $7.00 \times 10^{-9}$  to  $5.86 \times 10^{-5}$  mg/L/day for both adults and children (Table 3). All the estimated doses were lower than corresponding reference doses for ingestion and contact with the heavy metals in water, thus no serious health risks can result from contact and consumption of water from the sampled stations of the rivers.

For consumption of *P. annectens*, EDIs ranged from  $4.30 \times 10^{-2}$  to  $2.88 \times 10^0$  mg/kg/day for both children and adults. Most EDIs exceeded individual metal reference doses, implying that there are possible health risks from consumption of *P. annectens*. For non-carcinogenic risks, THQs were all below 1 for exposure through contact and ingestion of water by both children and adults (Additional file 1: Table S1). However, THQs for Mn and Pb were above 1 for adults while only Zn and Cr had  $\text{THQ} < 1$  for children. Thus, consumption of *P. annectens* from the studied parts of Nyabarongo river may have negative health impacts as TTHQs were greater than 1 in both adults and children.

Carcinogenic risks (CR), defined by US EPA as “the incremental probability of an individual to develop cancer, over a lifetime, as a result of exposure to a potential carcinogen” were estimated for Cr, Cd and Pb using ingestion cancer slope factor [24] (Additional file 2: Table S2). The range of risks borderline by US EPA is  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$  and is unacceptable if the risks are surpassing  $1 \times 10^{-4}$  [25]. Considering intake of Cr, Cd and Pb through ingestion and dermal contact with water, the total cancer risks were below the safety level ( $1 \times 10^{-4}$ ). Thus, there is no carcinogenic risk for both adults and children through ingestion and contact with water from the studied rivers. The CR for consumption of *P. annectens* contaminated with Cr, Cd and Pb ranged from  $1.84 \times 10^0$  to  $3.38 \times 10^2$  for both groups. These values were higher than  $1 \times 10^{-4}$ , suggesting that there are potential cancer risks from consumption of *P. annectens*.

#### Limitations

In this study, (i) the body weights and daily intakes were not estimated for Rwandese, (ii) ingested dose was considered to be equal to the absorbed dose, (iii) probability variables used were from US EPA guidelines which may not apply to this population, (iv) CR was estimated

for Cr, Cd and Pb only because there are no CSF values for the other heavy metals investigated, (v) CSF was considered as a constant for all individuals, but this is known to vary between individuals, and (vi) the health risks were only assessed using metal toxicity in the muscles, but water and fish contain other chemicals from possible exposure routes, and metabolically active organs of *P. annectens* may contain higher heavy metal concentrations. Thus, the level of health risks may be higher than estimated in this study.

#### Supplementary information

**Supplementary information** accompanies this paper at <https://doi.org/10.1186/s13104-020-4939-z>.

**Additional file 1: Table S1.** Target hazard quotients and non-carcinogenic health risks for ingestion and dermal contact with water and consumption of *P. annectens* from Nyabarongo and Nyabugogo rivers.

**Additional file 2: Table S2.** Cancer risks through ingestion and dermal contact with water and consumption of *P. annectens* by adults and children.

**Additional file 3: Table S3.** Raw data for physicochemical properties of water and the heavy metal content of the edible muscles of *Protopterus annectens* from Nyabarongo and Nyabugogo rivers.

#### Abbreviations

CR: Carcinogenic/cancer risk; EDI: Estimated daily intake; FAO: Food and Agriculture Organization of the United Nations; *P. annectens*: *Protopterus annectens*; R<sub>D</sub>: Reference dose; THQ: Target hazard quotient; TTHQ: Total target hazard quotient; US EPA: United States Environmental Protection Agency; UTEXRWA: Usine Textile Du Rwanda; WHO: World Health Organization.

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#### Authors' contributions

TO, PN and SA designed the study, PN performed the analytical experiments, TO, DWO, DMN, RO, SME, AJ and AM performed literature search, PN, LNK, BJK, SME and AJ analyzed the collected data. TO, PN, SA, DWO and RO wrote the first draft of the manuscript. All authors revised and approved the final manuscript.

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#### Availability of data and materials

The datasets supporting the conclusions of this study are included within the article (and its additional files).

#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.



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**References**

- Nhapi I, Wali UG, Uwongunda BK, Nsengimana H, Banadda N, Kimwaga R. Assessment of water pollution levels in the Nyabugogo catchment, Rwanda. *Open Environ Eng J*. 2011;4:40–53.
- Grinning planet. Polluted seas: major bodies of water/areas with serious water pollution problems. <http://grinningplanet.com/2005/07-26/polluted-seas.htm>. Accessed 20 Aug 2019.
- Omara T, Mbabazi I, Karanja LN, Nyangena DM, Nteziyaremye P, Jechirchir A. Poly-3-hydroxybutyrate biosynthesis by *Bacillus megaterium* utilizing a pleustophytic ecological plague in the legendary source of River Nile as the sole carbon source. *South Asian Res J Nat Prod*. 2019;2:1–8.
- Castro-González MI, Méndez-Armenta M. Heavy metals: implications associated to fish consumption. *Environ Toxicol Pharmacol*. 2008;26:263–71.
- Omara T, Karungi S, Kalukusu R, Nakabuye BV, Kagoya S, Musau B. Mercuric pollution of surface water, superficial sediments, Nile Tilapia (*Oreochromis nilotica* Linnaeus 1758 [Cichlidae]) and yams (*Dioscorea alata*) in auriferous areas of Namukombe stream, Syanyonja, Busia, Uganda. *PeerJ*. 2019;7:e7919.
- Omara T, Nassazi W, Adokorach M, Kagoya S. Physicochemical and microbiological quality of springs in Kyambogo university propinquity. *OALib J*. 2019;6:1–13.
- Omara T, Ogwang R, Ndyamuhaki S, Kagoya S, Kigenyi E, Musau B, et al. Spectroscopic analysis of selected priority trace metals in the extant East African gilled lungfish (*Protopterus amphibius*) in Lira municipal lagoon and its edibility health risk. *Sci J Anal Chem*. 2018;6:38–45.
- American Public Health Association (APHA). Standard methods for examination of water and wastewater, vol. 20. Washington: American Public Health Association; 1995.
- Ordóñez A, Alvarez R, Charlesworth S, De Miguel E, Loredó J. Risk assessment of soils contaminated by mercury mining, Northern Spain. *J Environ Monit*. 2011;13:128–36.
- AQUASTAT. 2008. Country fact sheet: Rwanda. FAO's global information system on water and agriculture. <http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/RWA>. 2008. Accessed 01 Dec 2019.
- National Institute of Statistics of Rwanda. 2019. Life expectancy at birth. <http://www.statistics.gov.rw/publication/life-expectancy-birth>. Accessed 14 Nov 2019.
- Wang X, Sato T, Xing B, Tao S. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. *Sci Total Environ*. 2005;350:28–37.
- US EPA. Risk-based concentration table. Washington: United States Environmental Protection Agency; 2009.
- WHO. Guidelines for drinking-water quality 3rd edition, first addendum to the 3rd edition, recommendations, vol. 1. Geneva: WHO; 2018.
- Ikape SI, Solomon SG, Ed-Idoko J. Proximate and macro element composition of four fish species from lower River Benue Makurdi Benue state Nigeria. *J Nutr Health Food Sci*. 2018;6:1–6.
- Alinnor IJ, Ayuk AA, Igbomezie MC. Distribution of elemental contaminants in water and fish samples from Oguta Lake, Nigeria. *Int J Fish Aquat Stud*. 2016;4:659–64.
- Alinnor IJ, Alagoa AF. Trace metal distribution in fish, sediment and water samples from Nkisa river, Nigeria. *Br J Appl Sci Technol*. 2014;20:2901–13.
- Atuanya EI, Edefetah MA, Nwogu NA. Microbiological qualities and some heavy metals (mercury and cadmium) levels of fresh and dry fish species sold in Benin city, Edo state, Nigeria. *Bull Environ Pharmacol Life Sci*. 2011;1:10–4.
- Nwani CD, Nwoye VC, Afiukwa JN, Eyo JE. Assessment of heavy metals concentrations in the tissues (gills and muscles) of six commercially important fresh water fish species of Anambra river South-East Nigeria. *Asian J Microbiol Biotechnol Environ Sci*. 2009;11:7–12.
- FAO/WHO. WHO technical report series No 505. Evaluation of certain food additives and the contaminants, mercury, lead and cadmium for environment monitoring report No 52 center for environment. Tech Rep, fisheries and aquaculture science lowest toft UK. 1989.
- Usanzineza D, Nhapi I, Wali UG, Kashaigili JJ, Banadda N. Nutrients inflow and levels in lakes: a case study of Lake Muhazi, Rwanda. *Ecol Dev Sum*. 2011;19:53–62.
- Muhirwa D, Nhapi I, Wali UG, Banadda N, Kashaigili JJ, Kimwaga R. Characterisation of wastewater from the Nyabugogo abattoir, Rwanda and the impact on downstream water quality. *Int J Ecol Dev*. 2010;16:30–46.
- Hakizimana P, Maniragaba A, Nshimiyimana FX. Assessment of heavy metals in *Amaranthus spinosus*, Kigali, Rwanda. *Int J Adv Res Publ*. 2019;3:7–12.
- USEPA. 2011. USEPA regional screening level (RSL) summary table. <http://www.epa.gov/regshwmd/risk/human/index.htm>. Accessed 10 Nov 2019.
- EPA. Edition of the drinking water standards and health advisories EPA 822-S-12-001. Washington: Office of water U.S. environmental protection agency; 2012. p. 2012.

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