ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/365625413

Physicochemical Quality and Health Risks Associated with Use of Water from Nyamwamba River, Kasese, Western Uganda

Article *in* Asian Journal of Applied Chemistry Research · November 2022

DOI: 10.9734/ajacr/2022/v12i2217

CITATIONS
6

READS
549

3 authors, including:

Denis Byamugisha
Mbarara University of Science & Technology (MUST)
15 PUBLICATIONS **133** CITATIONS

SEE PROFILE

Christopher Adaku
Mbarara University of Science & Technology (MUST)
23 PUBLICATIONS **82** CITATIONS

SEE PROFILE

All content following this page was uploaded by Christopher Adaku on 29 November 2022.

The user has requested enhancement of the downloaded file.

Asian Journal of Applied Chemistry Research

Volume 12, Issue 2, Page 19-33, 2022; Article no.AJACR.93884
ISSN: 2582-0273

Physicochemical Quality and Health Risks Associated with Use of Water from Nyamwamba River, Kasese, Western Uganda

Jockus Masereka [a*], Denis Byamugisha [a] and Christopher Adaku [a]

[a] *Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, P.O. Box 1410, Mbarara, Uganda.*

Authors' contributions

This work was carried out in collaboration among all authors. Authors JM, DB and CA designed the study. Author JM collected samples and performed the analytical work. Authors DB and CA supervised the study. Author JM analyzed the collected data and wrote the first draft of the manuscript. Authors DB and CA reviewed the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJACR/2022/v12i2217

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/93884

Original Research Article

Received: 09/09/2022
Accepted: 18/11/2022
Published: 21/11/2022

ABSTRACT

Aim: In Kasese district of Western Uganda, farmers cultivating near Nyamwamba River (NR) experience crop wilting whenever the river banks burst. Increased cases of cancer and ulcers in the district is anecdotally blamed on ingestion of contaminated water from water resources polluted by tailings from Kilembe copper mines. Sand miners attested that mining in NR caused body irritations and itching while drinking water from the same river results in abdominal complications in infants. The aim of this study was to assess the seasonal variations in the

**Corresponding author: Email: jockusm@gmail.com;*

physicochemical parameters and heavy metals (HMs) content of water from NR, and the associated health risks.

Place and Duration of Study: The experiments were done at the Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, Uganda from 2018 to 2019.

Methodology: This study employed quantitative research design. Water was sampled from down, middle and upstream of NR and Mubuku River, Western Uganda during the dry and wet seasons. The samples were analyzed for physicochemical parameters (pH, conductivity, total dissolved solids, total suspended soils) and HMs: chromium (Cr), cadmium (Cd), zinc (Zn), iron (Fe), lead (Pb), arsenic (As) and copper (Cu) by atomic absorption spectrometry. The estimated daily intake (EDI), target harzard quotient (THQ) and cancer risks were calculated to explore if there are any carcinogenic and non-carcinogenic health risks that could arise from ingestion and dermal contact with water from NR.

Results: Most physicochemical parameters of the water samples only met WHO guidelines for drinking water in the upstream. The mean concentration of Fe, Cu, Pb, Zn, Cr, Cd and As were 0.90-29.66 mg/L, 0.21-10.74 mg/L, 0.40-8.21 mg/L, 1.10-13.47 mg/L, 0.79-13.47 mg/L, 0.05-1.40 mg/L and 0.22-4.34 mg/L, respectively. Wet season recorded higher HMs concentrations when compared to the dry season, with all its samples exceeding the WHO guidelines for drinking water. There was an extremely high concentration of HMs in the upstream samples than expected. Health risk assessment indicated that the EDI through dermal contact ranged from 0.015 to 4.150 mg/kg/day while through ingestion of contaminated water, the values ranged from 0.008×10^{-6} to 38.266×10^{-6} mg/Lday. Some of the EDI doses were higher than corresponding reference doses for ingestion and contact with the HMs in water. THQ and total THQ exceeded 1 while cancer risk values were beyond the US EPA cancer risk borderline.

Conclusion: This study revealed that there are serious non-carcinogenic and carcinogenic health risks that could arise from consumption and contact with water from NR. Future studies should examine the relationship between the occurrence of trace metals in food stuffs with cancer, ulcers and other associated diseases in the area.

Keywords: Cancer risk; dermal adsorption; estimated daily intake; hazard index; target hazard quotient; trace metals.

1. INTRODUCTION

The stride to achieve industrialization and urbanization has introduced various environmental challenges [1,2]. Firstly, it has led to the destruction of landscape, ecosystems and exacerbated the climate change crisis [3,4]. Secondly, it has accelerated the introduction and transport of legacy contaminants, threatening the existence of humans, the environment and other organisms [5]. Common examples of anthropogenic environmental contaminants include active pharmaceutical ingredients, heavy metals (HMs), macro-, micro- and nanoplastics, endocrine disrupting chemicals, current use pesticides, preservatives and personal care products [6-8]. Within this frame of reference, HMs have been the most ubiquitous in the environment. For example, their mobilization and long-range transport in the environment was cited as early as the 1940s [9].

By definition, HMs are metallic chemical elements that have relatively high densities (five times or more) than water and are potentially toxic or poisonous at concentrations that exceed their threshold limits [10]. HMs are naturally part of the earth's crust but their enrichment are often due to anthropogenic influence [11]. They include typical metals and metalloids such as tin (Sn), mercury (Hg), vanadium (V) lead (Pb), zinc (Zn), nickel (Ni), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), molybdenum (Mo), strontium (Sr) and titanium (Ti) [10,12]. It is worth mentioning that some HMs (Cu, Fe and Zn) are required in trace amounts as co-enzymes in living organisms but may become bioaccumulative and toxic to living organisms at higher concentrations [13,14]. Humans are exposed to HMs in different ways namely: ingestion in water, medicine and foods, dermal contact or inhalation from occupational sources [15,16].

For the most part, ingestion of HMs occurs through intake of contaminated water or aquatic organisms. Thus, they need to be routinely monitored in order to control their contamination levels. In developing countries, environmental monitoring is sporadic due to limited resources.

In Africa, and particularly East Africa, there are various water resources (such as the Western Indian Ocean, Lake Victoria, Lake George and River Nile) which have been investigated and reported to be potentially contaminated with HMs [17-19].

In Uganda, River Nyamwamba (NR) is one of the major water resources used around Kilembe copper mines in Kasese district [18]. Several studies conducted around the abandoned Kilembe copper mine in Western Uganda incriminates it as the major source of HMs in water, food crops and sediments [18,20-23]. However, most studies did not consider the seasonal dynamics in HMs concentrations and health risk assessments from the use of water from NR. Farmers cultivating near NR experience crop wilting whenever the river banks burst, resulting in disastrous floods streaming in the low lands through the incised gorges and valleys [24-26]. Sand miners hinted that mining in NR has been associated with body irritations and itching. Others also hold that drinking water from NR resulted in abdominal complications in infants. Other reports cited that the pollution of NR equally impacts the Lake George basin, a Ramsar site [18,24]. Against the proposition that water from Mubuku River in the same district is uncontaminated when compared to NR, this study investigated the seasonal variations in HMs content of water from NR during the dry and wet seasons (after floods), and estimated the health risks associated with use of water from it.

2. MATERIALS AND METHODS

2.1 Study Area

Nyamwamba River (Fig. 1) is a water resource that is fed by melting glaciers originating from the mountains of the moon (the Rwenzori Montane region). An estimated distance of 126 km is stretched by the river and its tributaries before pouring into Lake George [27]. Nyamwamba River is traced to have been formed from seismic movements of the Western arm of the Great Rift Valley [28]. During the faulting formations of the Rwenzori Mountains, southward tilting led to the creation of an area of weakness at the confluence of the current Lake George and Kazinga channel faults resulting in a North-South drainage pattern. The pattern included the formation of rivers Kanyampara, Dwimbi, Chako and Dunglea as tributaries of NR in the peak areas of the Rwenzori Mountains [28-30]. Nyamwamba River causes flooding downstream on hot days when the mountain ice melts [31], and these are sometimes accompanied by landslides and volcanic activities of Rwenzori mountains [32]. Nyamwamba river is located in the propinquity of the now inactive Kilembe copper mine in Kasese district, Western Uganda. The lithology of the area is constituted by gneiss, mica schist with quartzite interbeds and moraine deposits [32].

2.2 Sampling and Sample Preparation

Water was purposively sampled from NR (n =18) and Mubuku River (n = 6; as a control) into 500 ml polypropylene bottles. Grab sampling was used, and all sampling was done between 10:00 a.m and 11:30 a.m (East African Standard Time) on July 2018 for dry season and November 2018 for wet season. Briefly, each bottle was rinsed thrice with water at the sampling sites, filled 20-25 cm below the water surface and capped with airtight stoppers while still under water. The samples were placed in a cooler box and submitted to the laboratory where they were stored at $4^{o}C$ until commencement of analysis.

2.3 Sample Analyses

Non-conservable parameters of the samples such as electrical conductivity (µS/cm), total dissolved solids (mg/L), and pH were measured on-site using calibrated Jenway pH/mV/Temperature and Conductivity meters (Jenway Gransmore Green, England). The other parameters: total suspended soilds (mg/L) and turbidity (mg/L) of the samples collected were analyzed in the laboratory.

The samples collected were labelled as upstream, downstream, control and middle stream samples, respectively. Measured 20 ml of each sample were filtered through Whatmann No. 42 filter paper in preparation for analysis. An atomic absorption spectrophotometer (Analyst 400, Perkins Elmer) equipped with photomultiplier tube detector and a hollow cathode lamp was used for the determination of metal concentrations. Working standards were also prepared by further dilution of 1000 ppm stock solution of the nitrate salts of the metals and a calibration curve was constructed by plotting absorbance versus concentration. By interpolation, the concentrations of the metals in sample digestates were determined.

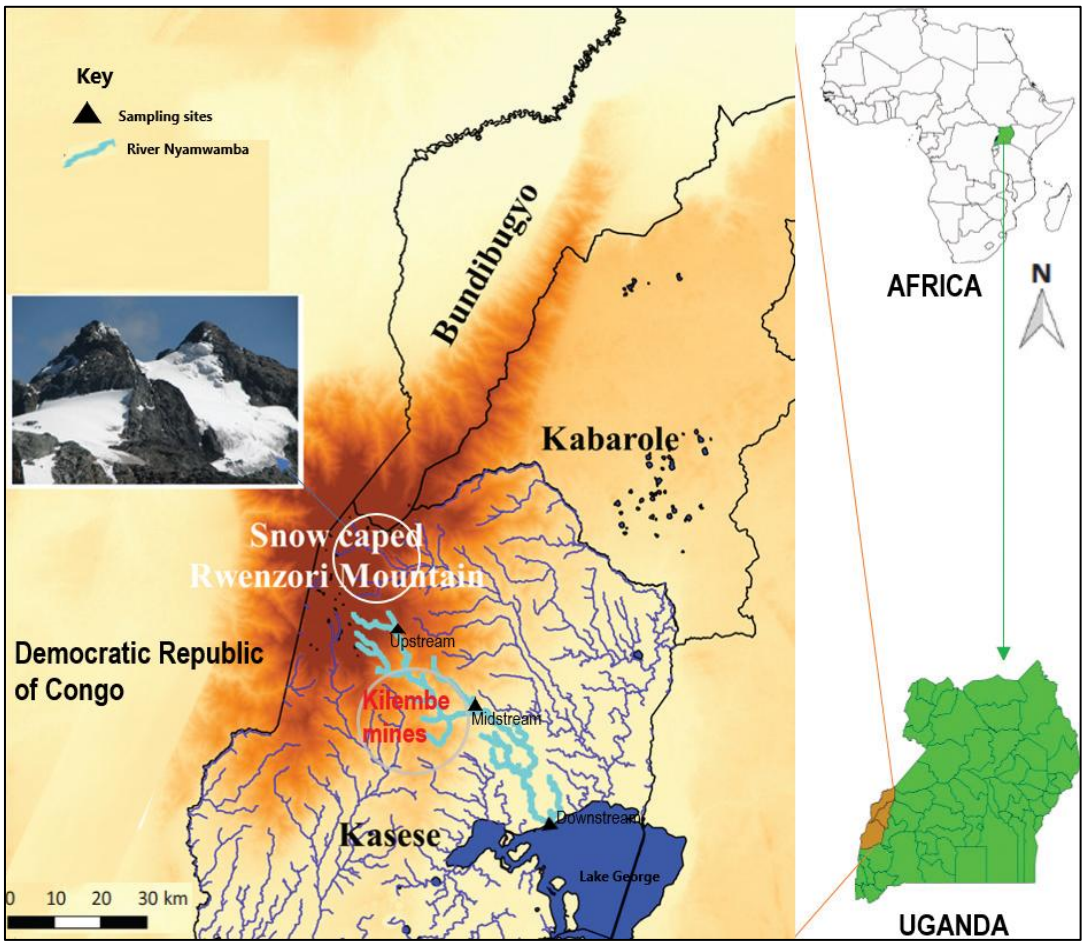

Fig. 1. Map showing the location of Nyamwamba river (0012'30.0" N, 30000'25.0" E) and Kilembe copper mine in Kasese district, Uganda. Inset is the location of Uganda in Africa and the study area in Uganda. Adapted from Bwambale et al. [27]

2.4 Human Health Risk Assessment

2.4.1 Estimated daily intake and target hazard quotient

The average daily doses (mg/kgday and mg/Lday) were computed for children (as a sensitive group) and adults (as the general population) to discern human exposure through direct ingestion (ADD_{ing}) and dermal contact (ADD_{derm}) with water (Equation 1 and Equation 2). The assertion was that sand mining occurs on R. Nyamwamba and the miners come into contact with HMs-contaminated water [16,33,34].

$$ADD_{ing} = \frac{C_m \times W_{ir} \times E_f \times E_d}{W_{ab} \times T_{aet}} \quad (1)$$

$$ADD_{derm} = \frac{C_m \times S_A \times DAF \times AF \times E_f \times E_d}{W_{ab} \times T_{aet}} \times 10^{-6} \quad (2)$$

Where in C_m = heavy metal concentration (mg/L), W_{ir} is the water ingestion rate = 1.8 L/day and 21.0 L/day for children and adults, S_A is the exposed surface area = 2,800 cm^2 for children and 24,350 cm^2 for adults [34], DAF is the dermal absorption factor = 0.01 for carcinogenic HMs and 0.001 for non-carcinogenic HMs [35], AF is the skin adherence factor in $mg/cm^2/day$ = 0.2 and 0.7 for children and adults [36], E_f = exposure frequency (365 days/year), E_d = exposure duration, the average lifetime (58.65 years for an adult Ugandan) [16,37], W_{ab} = average body weight (considered to be 15 kg for children and 60 kg for adults), T_{aet} is the average exposure time for non-carcinogens = $E_f \times E_d$ [38].

On the other hand, the target hazard quotient (THQ) was computed using Equation 3. Ideally, THQ ≤ 1 implies that the exposure is unlikely to exert adverse health effects whereas THQ > 1 represent a possibility of non-carcinogenic effects [36]. In this assessment, the augmentative effect of toxicants (the cumulative risk or total THQ) was considered as the sum of

the individual metal THQ values (Equation 4) [39]. The assumption made during the health risk calculations was that the ingested/adsorbed dose is equal to the dose absorbed into the body.

$$THQ = \frac{ADD_{ing}}{R_f Do} \quad \text{or } THQ = \frac{ADD_{therm}}{R_f Dd} \tag{3}$$

$$\text{Total } THQ = \sum_{i=1}^{n} THQ \tag{4}$$

Where R_fD_o is the oral reference dose while R_fD_d is the dermal reference dose [40]. The reference dose is the maximum daily dose of a metal from a specific exposure pathway, that is believed not to lead to an appreciable risk of deleterious effects to sensitive individuals during a life time [41]. Thus, if the average daily dose (ADD_{ing} or ADD_{derm}) is lower than the reference dose (R_fD_o or R_fD_d), the THQ < 1 and adverse health effects are unlikely to appear. Otherwise, an average daily dose greater than the reference dose is indicative that THQ > 1 and adverse health effects are likely to appear.

2.4.2 Cancer risk assessment

The cancer risk (CR) estimated as the incremental lifetime cancer risk for the carcinogenic heavy metals (Pb, Cd, Cr and As) were calculated as the product of ADD_{ing} and the ingestion cancer slope factor (CSF) using Equation 5. Consequently, the total cancer risk (TCR) from ingestion of the carcinogenic HMs in water was calculated using Equation 6 suggested by preceding authors [35,42].

$$CR = ADD_{ing} \times CSF \tag{5}$$

$$TCR = \sum_{i=1}^{n} CR \tag{6}$$

The CSF (mg/kgday) for Pb, Cr, Cd and As are 8.5×10^{-6}, 5.0×10^{-4}, 3.8×10^{-4} and 1.50×10^{0}, respectively.

2.5 Statistical Analysis

Quantitative data from analyses were entered into Excel and exported to SPSS where they were averaged. Significant differences of the spatial variations in water quality among the sampling sites along the river were evaluated using One-Way Analysis of Variance (One-Way ANOVA) with Tukey posthoc test. The analyses were executed at 95% confidence interval employing Minitab Statistical Software (version 21, Minitab Inc., USA).

3. RESULTS AND DISCUSSION

3.1 Seasonal Variations in Physicochemical Parameters of Water in Nyamwamba River

The pH, conductivity, total suspended solids (TSS), TDS and turbidity of the water samples are shown in Table 1. The mean pH values were within WHO limits of 6.5-8.5 except in the midstream during wet season [43]. The values were not significantly different between the dry and wet seasons, and that of Mubuku River. The pH values obtained in this study were comparable to 7.06 and 7.03, 6.2-8.0, 7.96-8.22, 6.6–7.5, 5.85-7.60 and 8.05-8.30 reported for water from NR [19,44], River Mohokare of Lesotho [45], Nyabugogo and Nyabarongo rivers, Rwanda [42], Aturukuku River [46], Nyamugasani River [47] and Rwimi River of Uganda [47,48]. Interestingly, the pH values were slightly higher than 5.60-6.32 and 5.58-6.80 reported for water sampled from NR and Mubuku River of Uganda reported by Mukisa et al. [48]. There is consensus that ingestion of excessively acidic or alkaline water may be harmful to the body. Even within the acceptable pH range, slightly high or low pH of water can be unpleasant. For example, high alkalinity confers a slippery feel to water, making it to taste like baking soda. At acidic pH, water have a bitter or metallic taste and may lead to fixture corrosion [49].

The other parameters measured only met WHO guidelines for drinking water in the upstream. Conductivity for example ranged from 37.9 to 1500 µS/cm. There were significant differences in the conductivities of water from NR during the dry and wet seasons ($P < 0.05$). Bakyayita et al. [19] and Mwongyera et al. [44] reported conductivity values of 127 µS/cm and 104 µS/cm for water from NR. The conductivity values recorded are in ranges of 12 to 946.08 µS/cm for water sampled from rivers: Lubigi, Nyamugasani, Sio, Rwimi, Victoria Nile, Mubuku, Lhubiriha, Rwimi and Nyamwamba in Uganda [47,50]. Similar high conductivity values (108-1524 µS/cm) were reported by Turinayo [51] for water samples drawn from Musamya River in Uganda. In Nyabugogo and Nyabarongo rivers of Rwanda, conductivity values in the range of 74.3-102.0 µS/cm were recorded [42]. Another investigation in Mohokare River water, Lesotho [45] reported conductivity of 2000-3800 µS/cm which are far higher than obtained in this study. In Nigeria, Butu et al. [52] found conductivity of

Rido River to range from 79 to 146.3 µS/cm, which are close to some values obtained in this study. The conductivity of water estimates the total amount of solids dissolved in water (its total dissolved solids) and is directly proportional to the water's temperature. It is directly related to the concentration of ions in the water, and this is supported by the elevated concentration of HMs reported in this study.

The mean concentrations of HMs of the analyzed water samples from NR are given in Table 1. The concentrations of the HMs in samples from the upstream (Kilembe mines) were significantly lower ($p < 0.05$) than concentrations along the mine area and downstream, illustrating that there was very significant contribution of the mine to the observed HMs concentrations. Further, the HMs concentration may have decreased due to the dilution from other rivers such as Ngangi and Kyanjuju flowing through the Kilembe valley joining NR [44]. These observations are in agreement with that of Mwesigye and Tumwebaze [23]. It can be observed that the wet season had higher levels of HMs than the dry season, possibly due to the leaching of adjacent soils which contributes to increase in the load of tailings transported by the river. With the exception of Fe, all the HMs surpassed the WHO guidelines for drinking water in the wet season. In the dry season, Cu, Fe and Zn (in samples from midstream and upstream) were the only HMs that did not exceed the WHO guidelines for drinking water. By comparison, the obtained HMs concentrations were higher than those from Mubuku River used as a control site in this study. The HMs concentrations reported in this study (except for Fe and Cd) were higher than those reported by Mwongyera et al. [44], Mwesigye et al. [21], Mwesigye and Tumwebaze [23], Bakyayita et al. [19], Kaweesa [20] and Mukisa et al. [48] in water from NR (Table 2).

Table 1. Hydrochemical properties of water from R. Nyamwamba and R. Mubuku, Kasese, Uganda during the dry and wet seasons

Season	Parameter	R. Nyamwamba			River Mubuku (control)	WHO guidelines
		Downstream (L. George)	Midstream	Upstream		
Wet season	pH	6.75	6.44	7.20	6.54	6.5-8.5
	Conductivity (µS/cm)	1278.0	3780.0	37.9	30.0	1000
	TDS (mg/L)	6580.0	2949.0	1937.0	1344.0	2000
	TSS	450.0	350.0	300.0	89.0	NEL
	Turbidity (NTU)	6.99	5.50	5.00	4.00	5.0
	Fe	29.66	34.58	10.21	6.02	NEL*
	Cu	10.74	0.96	5.29	2.50	2.00
	Pb	8.21	5.11	2.00	0.07	0.01
	Zn	13.47	10.49	5.56	1.05	3.00
	Cr	13.47	1.05	5.56	3.10	0.05
	Cd	1.40	1.08	0.44	0.12	0.003
	As	4.34	4.34	0.49	0.49	0.01
Dry season	pH	6.70	6.51	6.87	6.80	6.5-8.5
	Conductivity (µS/cm)	1100	1500	400	150	1000
	TDS (mg/L)	2580	2049	1215	144	2000
	TSS	150	100	120	52	NEL
	Turbidity (NTU)	6.99	5.5	5	4	5.0
	Fe	2.60	3.80	1.09	0.90	NEL*
	Cu	0.21	0.88	0.37	0.54	2.00
	Pb	0.92	0.51	0.40	0.20	0.01
	Zn	6.47	1.10	2.56	0.79	3.00
	Cr	6.45	0.79	2.56	1.10	0.05
	Cd	0.11	0.18	0.05	0.01	0.003
	As	0.56	0.22	3.34	0.23	0.01

**NEL = No established permissible limit in drinking water. Values in bold indicate exceedance of WHO limits*

Table 2. Comparison of the results of HMs in water from the current study with previous studies

River (Country)	Fe	Cu	Pb	Zn	Cr	Cd	As	References
R. Nyamwamba (Uganda)	0.90-29.66	0.21-10.74	0.40-8.21	1.10-13.47	0.79-13.47	0.05-1.40	0.22-4.34	This study
	1.21	ND	ND	ND	ND	ND	ND	Bakyayita et al. [19]
	ND	ND	16.0	ND	ND	61.0	ND	Kaweesa [20]
	185.0-265.0	1.9-61.0	0.27-0.40	ND	ND	ND	0.12-1.50	Mwesigye and Tumwebaze [23]
	ND	0.0006-0.052	0.0002-0.0012	0.0029-0.0208	ND	0.00001-0.00004	0.0001-0.0002	Mwesigye et al. [21]
	ND	0.09	BDL	0.01	ND	BDL	ND	Mwongyera et al. [44]
	ND	0.740	0.047	0.076	ND	ND	ND	Mukisa et al. [48]
River Rwimi (Uganda)	ND	0.010	0.067	0.01	ND	ND	ND	
River Mubuku (Uganda)	ND	0.025	0.053	0.01	ND	ND	ND	
	0.90-6.02	0.54-2.50	0.07-0.20	0.79-1.05	1.10-3.10	0.01-1.02	0.23-0.49	This study
Nyabarongo river (Rwanda)	0.63-1.61	BDL-0.24	0.05-0.75	BDL-0.09	BDL-0.06	BDL-0.106	ND	Omara et al. [42]; Nteziyaremye and Omara [11]
Nyabugogo river (Rwanda)	1.57	0.29	0.59	0.43	0.15	BDL	ND	Omara et al. [42]
Sosiani river (Kenya)	0.011-3.789	0.001-0.275	0.02-1.89	0.07-0.57	0.003-0.05	ND	ND	Amadi [53]
Dzindi, Madanzhe and Mvudi rivers (South Africa)	ND	0.002–0.003	0.0105–0.0201	0.0021–0.0025	ND	0.0016–0.0093	ND	Okonkwo et al. [54]
Marimba River (Zimbabwe)	5.6-6.9	0.13-0.14	0.213-0.544	ND	ND	ND	ND	Mvungi et al. [55]

ND: Not determined. BDL: Below method detection limit

Of the HMs, Fe occurred at the highest concentration of 34.58 mg/L. This is in consonance with a previous finding that Fe is a major inorganic water quality problem and is mainly transported in groundwater in the ferrous form [56]. Generally, Fe is found in natural fresh water at levels ranging from 0.5 to 50 mg/L [57]. The high levels of Fe reported in this study agreed with previous studies. For example, Nhapi et al. [58] reported elevated Fe levels in water from Rwandese Rusine river (8.76 mg/L) and Marenge river (6.85 mg/L). Other reports by Omara et al. [59], Nteziyaremye and Omara [11] found very high concentrations of Fe in water from Nyabugogo and Nyabarongo rivers, Rwanda. These studies speculated that the high Fe pollution could have stemmed from the geological composition of red (eutrophic red clay) soils in the area. Amadi [53], Eliku and Leta [60] reported lower Fe concentrations (0.011 to 2.897 mg/L and 1.11 to 4.12 mg/L) in water from Sosiani river (Kenya) and Awash river (Ethiopia) than is reported in NR by this study. Elevated levels of Fe in water (12.6 to 15.51 mg/L) comparable to that reported in this study were reported in Mara river of Tanzania by Kihampa and Wenaty [61]. The high levels of Fe reported in this study could be due to iron, steel and household equipment made of iron that are dumped in the river or the effect of the mining of copper at the Kilembe copper mines. Specifically, the dark brown color of the river water observed during sampling could be attributed to the oxidation of iron in the ferrous form to ferric form and the formation of ferric hydroxide colloids and complexes as reported previously [62].

Similarly, Pb occurred at concentrations surpassing WHO maximum limits. Similar high Pb concentrations were reported in Mpazi river, Nyabarongo and Nyabugogo rivers, Rwanda [11,58,59], Marimba river, Zimbabwe [55], Dzindi, Madanzhe and Mvudi rivers, South Africa [54]. The prevalence of Pb in water resources stems from the use of leaded gasoline and lead-based paints and thoughtless dumping of dead car lead acid accumulators [63-65]. Lead is a toxic non-essential trace metal and the concentrations found in R. Nyamwamba may be harmful to humans when ingested [66]. Overall, the differences observed in the concentration of the HMs reported in water from rivers across the globe and the current study could be due to differences in geological formation of the rivers, their physicochemical conditions and potential sources of contamination [11,58].

3.2 Health Risk Assessment Results

The United States Environmental Protection Agency (US EPA) suggested that the human health risk assessment model should estimate potential health risks of contaminants based on exposure and toxicity. Health risk assessment establishes the link between the environment and human health that can be expressed quantitatively in terms of hazard degree. In this study, the carcinogenic and non-carcinogenic health risks were calculated separately for adults as the general population and children as a sensitive group. As per the US EPA model for estimating (carcinogenic and non-carcinogenic) human health risks, and human exposure to toxic elements, it was assumed that (i) the target population is divided into children and adults; (ii) the inhabitants at the sampling sites are potentially exposed; (iii) ingestion, inhalation, and dermal contact are the exposure routes to the HMs; (iv) non-carcinogenic risks were estimated for trace elements, and (v) cancer risks were estimated for carcinogenic elements (Pb, Cd, Cr and As).

The daily dose through dermal contact ranged from 0.015 to 4.150 mg/kgday while through ingestion of contaminated water, the values ranged from 0.008×10^{-6} to 38.266×10^{-6} mg/Lday (Table 3). Some of the calculated daily doses were higher than the corresponding reference doses for ingestion and contact. On the other hand, the target hazard indices through ingestion of contaminated water ranged from 0.024 for chromium ingested by adults upstream to 1,736.667 for As ingested by children midstream in the wet season (Table 4). For dermal contact, the target hazard quotients ranged from 0.003×10^{-6} for Fe ingested by children upstream to $637{,}766.667 \times 10^{-6}$ for Cr ingested by adults downstream in the wet season. Despite the fact that the THQ did not exceed 1 in some cases, the TTHQ exceeded 1 in most cases of ingestion. These results indicate that there potential non-carcinogenic health risks from consumption and coming into contact with water from NR which is in agreement with the anecdotal reports in the area [24,25].

Carcinogenic risks 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. For carcinogenic health risks (Table 5), the cancer

Table 3. Estimated daily doses through dermal contact and ingestion of water from Nyamwamba river

Period	Group	Metal	ADD_{ing} (mg/kg day)			Oral reference dose (mg/kgday)	ADD_{derm} ($\times 10^{-6}$ mg/Lday)			Dermal reference dose (mg/Lday)
			Downstream	Midstream	Upstream		Downstream	Midstream	Upstream	
Wet season	Children	Fe	3.559	4.150	1.225	7×10^{-1}	1.107	1.291	0.382	1.4×10^{2}
		Cu	1.285	0.115	0.635	4.0×10^{-2}	0.401	0.035	0.197	1.0×10^{-2}
		Pb	0.985	0.613	0.240	4.0×10^{-3}	3.065	1.908	0.747	5.25×10^{-4}
		Zn	1.616	1.259	0.667	3.0×10^{-2}	0.503	0.392	0.208	6.0×10^{-4}
		Cr	1.616	0.126	0.667	1.5×10^{0}	5.029	0.392	2.076	6.0×10^{-5}
		Cd	0.168	0.130	0.053	1.0×10^{-3}	0.523	0.403	0.164	6.0×10^{-5}
		As	0.063	0.521	0.059	3.0×10^{-4}	1.620	1.620	0.183	2.85×10^{-4}
	Adults	Fe	1.038	1.210	0.357	7×10^{-1}	8.426	9.824	2.900	1.4×10^{2}
		Cu	0.376	0.034	0.185	4.0×10^{-2}	3.051	0.272	1.503	1.0×10^{-2}
		Pb	0.287	0.179	0.070	4.0×10^{-3}	23.323	14.517	5.682	5.25×10^{-4}
		Zn	0.471	0.367	0.195	3.0×10^{-2}	3.827	2.980	1.580	6.0×10^{-4}
		Cr	0.471	0.037	0.195	1.5×10^{0}	38.266	2.983	15.795	6.0×10^{-5}
		Cd	0.049	0.038	0.015	1.0×10^{-3}	3.977	3.068	1.250	6.0×10^{-5}
		As	0.152	0.152	0.017	3.0×10^{-4}	12.329	12.329	1.392	2.85×10^{-4}
Dry season	Children	Fe	0.312	0.456	0.131	7×10^{-1}	0.097	0.142	0.041	1.4×10^{2}
		Cu	0.025	0.106	0.044	4.0×10^{-2}	0.008	0.033	0.014	1.0×10^{-2}
		Pb	0.110	0.061	0.048	4.0×10^{-3}	0.343	0.190	0.149	5.25×10^{-4}
		Zn	0.776	0.132	0.307	3.0×10^{-2}	0.242	0.041	0.096	6.0×10^{-4}
		Cr	0.774	0.095	0.307	1.5×10^{0}	2.408	0.295	0.956	6.0×10^{-5}
		Cd	0.013	0.022	0.006	1.0×10^{-3}	0.041	0.067	0.019	6.0×10^{-5}
		As	0.067	0.026	0.401	3.0×10^{-4}	0.209	0.082	1.247	2.85×10^{-4}
	Adults	Fe	0.091	0.133	0.038	7×10^{-1}	0.738	1.080	0.540	1.4×10^{2}
		Cu	0.007	0.031	0.013	4.0×10^{-2}	0.060	0.250	0.105	1.0×10^{-2}
		Pb	0.032	0.018	0.014	4.0×10^{-3}	2.614	1.449	0.136	5.25×10^{-4}
		Zn	0.226	0.038	0.090	3.0×10^{-2}	1.838	0.312	0.727	6.0×10^{-4}
		Cr	0.226	0.028	0.090	1.5×10^{0}	18.323	2.244	7.27	6.0×10^{-5}
		Cd	0.004	0.006	0.002	1.0×10^{-3}	0.312	0.5113	0.142	6.0×10^{-5}
		As	0.020	0.008	0.117	3.0×10^{-4}	1.591	0.625	9.488	2.85×10^{-4}

Values in bold indicate exceedance of the reference oral doses. Reference doses are from US EPA [40]

Table 4. Target hazard quotients for dermal contact and ingestion of water from R. Nyamwamba

Period	Group	Metal	THQ_{ing}			THQ_{derm} ($\times 10^{-6}$)		
			Downstream	**Midstream**	**Upstream**	**Downstream**	**Midstream**	**Upstream**
Wet season	Children	Fe	5.084	5.929	1.743	0.008	0.009	0.003
		Cu	32.125	2.875	15.875	40.100	3.500	197.000
		Pb	246.250	153.25	60.000	5,838.095	3,634.286	1,422.857
		Zn	53.868	41.967	22.233	838.333	653.333	346.667
		Cr	1.077	0.084	0.445	83,816.667	6,533.333	34,600.000
		Cd	168.000	130.000	53.000	8,716.667	6,716.667	2,733.333
		As	210.000	1,736.667	196.667	5,684.211	5,684.211	642.105
		TTHQ	*716.404*	*2,070.688*	*349.963*	*104,934.081*	*23,225.339*	*351,341.965*
	Adults	Fe	1.483	1.729	0.510	6.019	7.017	2.071
		Cu	9.400	0.850	4.625	305.100	27.200	150.300
		Pb	71.750	44.750	17.500	44,424.762	27,651.429	10,822.857
		Zn	15.700	12.233	6.500	6,378.333	4,966.667	2,633.333
		Cr	0.314	0.037	0.024	637,766.667	49,716.667	263,250.000
		Cd	49.000	38.000	15.000	66,283.333	51,133.333	20,833.333
		As	506.667	506.667	56.667	43,259.649	43,259.649	4,884.211
		TTHQ	*654.314*	*604.266*	*100.826*	*792,045.530*	*127,045.295*	*302,576.105*
Dry season	Children	Fe	0.446	0.651	0.187	6.929	10.143	2.929
		Cu	0.625	2.650	1.100	0.800	3.300	1.400
		Pb	27.500	15.250	12.000	653.333	361.905	283.810
		Zn	25.867	4.400	10.233	403.333	68.333	160.000
		Cr	0.516	0.063	0.205	40,133.333	4,916.667	15,933.333
		Cd	13.000	22.000	6.000	683.333	1,116.667	316.667
		As	223.333	86.667	1,336.700	733.333	287.719	4,375.439
		TTHQ	*291.287*	*131.681*	*1,366.220*	*42,614.394*	*6,764.734*	*21,073.578*
	Adults	Fe	0.130	0.190	0.054	0.0005	0.008	0.0039
		Cu	0.175	0.775	0.325	6.000	25.000	10.500
		Pb	8.000	4.500	3.500	4,979.048	2,760	259.048
		Zn	7.500	1.267	3.000	3,063.333	520.000	1,211.667
		Cr	0.177	0.019	0.060	303,866.667	37,400.000	121,166.667
		Cd	4.000	6.000	2.000	5,200.000	8,521.667	2,366.667
		As	66.667	26.667	390.000	5,582.456	2,192.982	33,291.228
		TTHQ	*86.649*	*39.418*	*398.939*			

Values in bold exceeds 1, indicating potental non-carcinogenic health risks

Table 5. Cancer risks through ingestion of contaminated water from Nyamwamba river, Uganda

Period	Group	Metal	Cancer risk		
			Downstream	Midstream	Upstream
Wet season	Children	Pb	8.373E-6	5.211E-6	2.040E-6
		Cr	8.08E-4	0.630E-4	3.335E-4
		Cd	0.638E-4	0.494E-4	0.201E-4
		As	9.450E-2	7.815E-1	8.850E-2
	Total cancer risk		9.595E-2	7.8263E-1	8.904E-2
	Adults	Pb	2.440E-6	1.522E-6	0.595E-6
		Cr	2.355E-4	0.185E-4	0.975E-4
		Cd	0.186E-4	0.144E-4	0.057E-4
		As	2.280E-1	2.280E-1	2.550E-2
	Total cancer risk		2.284E-1	2.228E-1	2.561E-2
Dry season	Children	Pb	0.935E-6	0.519E-6	0.408E-6
		Cr	3.870E-4	0.475E-4	1.535E-4
		Cd	0.049E-4	0.084E-4	0.023E-4
		As	1.005E-1	4.050E-2	6.015E-2
	Total cancer risk		1.009E-1	4.056E-2	6.033E-2
	Adults	Pb	0.272E-6	0.153E-6	0.119E-6
		Cr	1.130E-4	0.140E-4	0.450E-4
		Cd	0.015E-4	0.023E-4	0.008E-4
		As	3.000E-2	1.200E-2	1.755E-1
	Total cancer risk		3.013E-2	1.202E-2	1.756E-1

Note: Values in bold are above the safety level (1×10^{-4}) recommended by US EPA

risk values through ingestion of the HMs ranged from 0.119×10^{-6} for Pb ingested by adults to 7.815×10^{-1} for As ingested by children. Thus, the cancer risks were above the safety level (1×10^{-4}) for As ingested by both children and adults. The range of risks borderline by US EPA is 1×10^{-4} to 1×10^{-6} and is unacceptable if the risks are surpassing 1×10^{-4}. Thus, there are carcinogenic health risks for both adults and children through ingestion of water from NR.

It should be emphasized that this study has the following limiations. Firstly, the body weights and daily intakes were not estimated for Ugandans. Secondly, the ingested dose was considered to be equal to the absorbed dose. Thirdly, the probability variables used were from US EPA guidelines which may not apply to this population. Forthly, the canncer risk was estimated for Pb, Cr, Cd and As only because there are no CSF values for the other non-carcinogenic HMs investigated. In addition, CSF was considered as a constant for all individuals but this is known to vary between individuals. Lastly, the health risks were only assessed using metal toxicity in water, but the water may contain other chemicals from possible exposure routes. Thus, the level of health risks may be higher than estimated in this study. It is recommended that the risk characterizations should be cumulative to account for aggregate exposures to multiple compounds or mixtures causing similar toxicological effects.

4. CONCLUSION

This study has revealed that water in the whole stretch of Nyamwamba river is contaminated with heavy metals. Iron occurred at the highest concentration, and the contamination levels of the river are significantly higher during the wet season than the dry season. With the exception of Fe, all the HMs surpassed the WHO guidelines for drinking water in the wet season. This suggests that there is strong contamination by mining tailings discarded along the river. These tailings, containing a high concentration of HMs, are the main indication of manifestation of health symptoms in the riverside population. Health risk assessments indicated that there are potential carcinogenic and non-carcinogenic effects that could arise from drinking and dermal contact with water in the river as the total THQ exceeded 1 in most cases of ingestion and cancer risk values surpassed range of risks borderline by US EPA (1×10^{-4} to 1×10^{-6}). Thus, there is need for the regulatory authorities to put in place measures to remediate the area that is the source of these pollutants into the river.

ACKNOWLEDGEMENT

The authors are grateful for the contribution of the entire staff of Chemistry Department, Mbarara University of Science and Technology, Mbarara during the design and execution of the research activities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Angiro C, Abila PP, Omara T. Effects of industrial effluents on the quality of water in Namanve stream, Kampala Industrial and Business Park, Uganda. BMC Res Notes. 2020;13(1):220.
2. Patnaik R. Impact of industrialization on environment and sustainable solutions – reflections from a South Indian region. IOP Conference Series: Earth and Environmental Science. 2018;120:012016.
3. Marcantonio R, Javeline D, Field S, Fuentes A. Global distribution and coincidence of pollution, climate impacts, and health risk in the Anthropocene. PLoS ONE. 2021;16(7):e0254060.
4. Ford HV, Jones NH, Davies AJ, Godley BJ, Jambeck JR, Napper IE, et al. The fundamental links between climate change and marine plastic pollution. Sci Total Environ. 2022;806:150392.
5. Ahmed F, Ali I, Kousar S, Ahmed S. The environmental impact of industrialization and foreign direct investment: Empirical evidence from Asia-Pacific region. Environ Sci Pollut Res. 2022;29:29778–29792.
6. Nur-E-Alam M, Salam MA, Dewanjee S, Hasan MF, Rahman H, Rak AE, et al. Distribution, concentration, and ecological risk assessment of trace metals in surface sediment of a tropical Bangladeshi Urban river. Sustainability. 2022;14:5033.
7. Hassaan MA, El Nemr A. Pesticides pollution: Classifications, human health impact, extraction and treatment techniques. Egyptian J Aquat Res. 2020;46:207-220.
8. Shehu Z, Nyakairu GWA, Tebandeke E, Odume ON. Overview of African water resources contamination by contaminants of emerging concern. Sci Total Environ. 2022;852:158303.
9. Khan FU, Rahman AU, Jan A, Riaz M. Toxic and trace metals (Pb,Cd,Zn,Cu,Mn,Ni,Co andCr) in dust, dustfall/soil. J Chem Soc Pakistan. 2004;26(4):453–456.
10. Ali H, Khan E, Ilahi I. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. J Chem. 2019;2019:6730305.
11. Nteziyaremye P, Omara T. Bioaccumulation of priority trace metals in edible muscles of West African lungfish (protopterus annectens owen, 1839) from Nyabarongo river, Rwanda. Cogent Environ Sci. 2020;6:1779557.
12. Edelstein M, Ben-Hur M. Heavy metals and metalloids: Sources, risks and strategies to reduce their accumulation in horticultural crops. Scientia Hort. 2018;234:431-444.
13. Lall SP, Kaushik SJ. Nutrition and metabolism of minerals in fish. Animals. 2021;11(9):2711.
14. Soetan KO, Olaiya CO, Oyewole OE. The importance of mineral elements for humans, domestic animals and plants: A review. Afri J Food Sci. 2010;4(5):200-222.
15. Balali-Mood M, Naseri K, Tahergorabi Z, Khazdair M, Sadeghi M. Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Front Pharmacol. 2021;12:643972.
16. Omara T, Karungi S, Kalukusu R, Nakabuye B, 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.
17. Mamboya FA, Pratap HB, Björk M. Heavy metal contamination in the Western Indian Ocean (a review). Journal de Physique IV (Proceedings). 2003;107:1437.
18. Hartwig T, Owor M, Muwanga A, Zachmann D, Pohl W. Lake George as a sink for contaminants derived from the Kilembe copper mining area, Western Uganda. Mine Water Environ. 2005;24:114–123.
19. Bakyayita GK, Norrström AC, Kulabako RN. Assessment of levels, speciation, and toxicity of trace metal contaminants in selected shallow groundwater sources, surface runoff, wastewater, and surface water from designated streams in lake Victoria Basin, Uganda. J Environ Public Health. 2019;2019:6734017.
20. Kaweesa B. Determination of heavy metal concentration in water and food around river Nyamwamba. BSc Thesis, Makerere University, Kampala, Uganda; 2019.

21. Mwesigye AR, Young SD, Bailey EH, Tumwebaze SB. Population exposure to trace elements in the Kilembe copper mine area, Western Uganda: A pilot study. Sci Total Environ. 2016;573:366–375.
22. Owor M, Hartwig T, Muwanga A, Zachmann D, Pohl W. Impact of tailings from the Kilembe copper mining district on lake George, Uganda. Environ Geol. 2007;51:1065–1075.
23. Mwesigye AR, Tumwebaze SB. Water contamination with heavy metals and trace elements from Kilembe copper mine and tailing sites in Western Uganda; Implications for domestic water quality. Chemosphere. 2017;169:281–287.
24. Nation Media Group. Nyamwamba river pollution worries Rwenzori residents; 2018. Available:https://www.monitor.co.ug/uganda/news/national/nyamwamba-river-pollution-worries-rwenzori-residents-1734966.
25. New Vision. Causes of river Nyamambwa floods; 2014. Available:https://www.newvision.co.ug/news/1336451/causes-river-nyamambwa-floods.
26. Awori EH. Flood modelling of river Nyamwamba using HEC HMS/RAS: A case study of Kasese District. BSc Thesis, Busitema University, Tororo, Uganda; 2015.
27. Bwambale B, Muhumuza M, Nyeko M. Traditional ecological knowledge and flood risk management: A preliminary case study of the Rwenzori. Jàmbá. 2018;10(1):a536.
28. Bwebare B, Kariitu G, Kichodo H. The physical geography of Uganda: A Complete Approach for UACE Schools. (1st ed.). Kampala: Fountain Publishers; 2008.
29. DWRM. River Nyamwamba action plan: An assessment and response to the floods. Kampala, Uganda: Directorate of Water Resources Management; 2015.
30. Kimera D, Tumwijukye S. Early river flood-warning system based on embedded systems. East Afr J Eng. 2022;5(1):1-27.
31. Twebaze P. River Nyamwamba at the verge of extinction. Will there still be life in Kasese? 2015. Available:http://www.climatefrontlines.org/blog/river-nyamwamba-verge-extinction-will-there-still-be-life-kasese.
32. Jacobs L, Maes J, Mertens K, Sekajugo J, Thiery W, van Lipzig N, et al. Flash floods in the Rwenzori mountains—focus on the May 2013 multi-hazard Kilembe event. In: Mikoš M, Casagli N, Yin Y, Sassa K (eds). Advancing Culture of Living with Landslides. WLF 2017. Springer, Cham. 2017:631–641.
33. Nowell L, Moran P, Gilliom R, Calhoun D, Ingersoll C, Kemble N, et al. Contaminants in stream sediments from seven United States metropolitan areas: Part I: distribution in relation to urbanization. Archiv Environ Contam Toxicol. 2013;64:32–51.
34. Ordonez A, Alvarez R, Charlesworth S, De Miguel E, Loredo J. Risk assessment of soils contaminated by mercury mining, Northern Spain. J Environ Monit. 2011;13:128.
35. Alidadi H, Tavakoly Sany SB, Zarif Garaati Oftadeh B, Mohamad T, Shamszade H, Fakhari M. Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran. Environ Health Prevent Med. 2019;24(1):59.
36. Wojciechowska E, Nawrot N, Jolanta WM, Matej-Łukowicz K, Pazdro K. Heavy metals in sediments of urban streams: Contamination and health risk assessment of influencing factors. Sustainability. 2019;11:563.
37. Bamuwamye M, Ogwok P, Tumuhairwe V, Eragu R, Nakisozi H, Ogwang P. Dietary content and potential health risks of metals in commercial black tea in Kampala (Uganda). J Food Res. 2017;6:1-12.
38. Saha N, Zaman M. Evaluation of possible health risks of heavy metals by consumption of foodstuffs available in the central market of Rajshahi city, Bangladesh. Environ Monit Assess. 2012;185:3867–78.
39. Sharma SD. Risk assessment via oral and dermal pathways from heavy metal polluted water of Kolleru lake - a Ramsar wetland in Andhra Pradesh, India. Environ Anal Health Toxicol. 2020;35(3):2020019.
40. US EPA. Risk-based concentration table. United States Environmental Protection Agency: Washington, DC; 2009.
41. Qing X, Yutong Z, Shenggao L. Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. Ecotoxicol Environ Safety. 2015;120:377–385.
42. Omara T, Nteziyaremye P, Akaganyira S, Opio D, Karanja L, Nyangena D, et al. Physicochemical quality of water and

health risks associated with consumption of African lung fish (Protopterus annectens) from Nyabarongo and Nyabugogo rivers, Rwanda. BMC Res Notes. 2020;13(1):66.
43. WHO, Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum. World Health Organization; 2017.
44. Mwongyera A, Mbabazi J, Muwanga A, Ntale M, Kwetegyeka J. Impact of the disused Kilembe mine pyrites on the domestic water quality of Kasese town, Western Uganda. Carib J Sci Technol. 2014;2:482-495.
45. Chatanga P, Ntuli V, Mugomeri E, Keketsi T, Chikowore NVT. Situational analysis of physico-chemical, biochemical and microbiological quality of water along Mohokare river, Lesotho. Egypt J Aquat Res. 2019;45:45–51.
46. Ochieng H, Odong R, Okot-Okumu J. Comparison of temperate and tropical versions of Biological Monitoring Working Party (BMWP) index for assessing water quality of river Aturukuku in Eastern Uganda. Global Ecol Conserv. 2020;23:e01183.
47. Busulwa HS, Bailey RG. Aspects of the physico-chemical environment of the Rwenzori rivers, Uganda. Afr J Ecol. 2004;42:87–92.
48. Mukisa W, Yatuha J, Andama M, Aventino K. Heavy metal pollution in the main rivers of Rwenzori region, Kasese district South-Western Uganda. Octa J Environ Res. 2020;8(3):078-090.
49. Omara T, Nassazi W, Adokorach M, Kagoya S. Physicochemical and microbiological quality of springs in Kyambogo University Propinquity. OALib. 2019;6:e5100.
50. Bwire G, Sack DA, Kagirita A, Obala T, Debes AK, Ram M, et al. The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of Uganda: An analysis of vital physicochemical parameters. BMC Publ Health. 2020;20(1):1128.
51. Turinayo YK. Physicochemical properties of sugar industry and molasses based distillery effluent and its effect on water quality of river Musamya in Uganda. Int J Environ Agric Biotechnol. 2017;2(3):1064-1069.
52. Butu AW, Emeribe CN, Muoka IO, Emeribe OF, Ogbomida ET. Downstream effects of industrial effluents discharge on some physicochemical parameters and water quality index of river Rido, Kaduna state, Nigeria. Trop Aqua Soil Pollut. 2022;2(2):90–108.
53. Amadi EK. Nutrient loads and heavy metals assessment along Sosiani river, Kenya. Chem Mat Res. 2013;3(12):14–20.
54. Okonkwo JO, Mothiba M. Physico-chemical characteristics and pollution levels of heavy metals in the rivers in Thohoyandou, South Africa. J Hydrol. 2005;308:122-127.
55. Mvungi A, Hranova RK, Love D. Impact of home industries on water quality in a tributary of the Marimba river, Harare: implications for urban water management. Phys Chem Earth. 2003;28(20-27):1131-1137.
56. BGS. Groundwater Quality: Uganda, London, British Geological Survey, Nottingham, UK, USA. 2001.
57. WHO. Guidelines for drinking-water quality,'' third edition, incorporating first addendum (third edition); 2004.
58. Nhapi I, Wali UG, Uwonkunda 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.
59. Nakiguli CK, Ojok W, Omara T, Wasswa J, Ntambi E. Mobility of chromium, copper and arsenic in amended chromated copper arsenate contaminated soils. Asian J Appl Chem Res. 2020;6:33-48.
60. Eliku T, Leta S. Spatial and seasonal variation in physicochemical parameters and heavy metals in Awash river, Ethiopia. Appl Water Sci. 2018;8:177.
61. Kihampa C, Wenaty A. Impact of mining and farming activities on water and sediment quality of the Mara river basin, Tanzania. Res J Chem Sci. 2013;3(7):15–24.
62. Chu L, Cheung K, Wong M. Variations in the chemical properties of landfill leachate. Environ Manage. 1994;18:105–117.
63. 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.

64. Huang X, Luo D, Zhao D, Li N, Xiao T, Liu J, et al. Distribution, source and risk assessment of heavy metall (oid)s in water, sediments, and corbicula fluminea of Xijiang river, China. Int J Environ Res Public Health. 2019;16:1823.
65. Algül F, Beyhan M. Concentrations and sources of heavy metals in shallow sediments in lake Bafa, Turkey. Sci Rep. 2020;10:11782.
66. Badr AM, Mahana NA, Eissa A. Assessment of heavy metal levels in water and their toxicity in some tissues of nile tilapia (*Oreochromis niloticus*) in river Nile Basin at greater Cairo, Egypt. Global Veterinaria. 2014;13(4):432-43.

© 2022 Masereka et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/93884

View publication stats