Original Research Article

Physicochemical quality and health risks associated with use of water from River Nyamwamba, Kasese, Western Uganda

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ABSTRACT

Aim: In Kasese district of Western Uganda, farmers cultivating near River Nyamwamba (R. Nyamwamba) 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 R. Nyamwamba caused body irritations and itching while drinking water from the river resulted in abdominal complications in infants. The aim of this study was therefore to assess the seasonal variations in the physicochemical parameters and heavy metals (HMs) content of water from R. Nyamwamba, and the associated health risks.
Study design: This study employed quantitative research design.
Place and Duration of Study: The experiments were done at the Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, P.O. Box 1410, Mbarara, Uganda from 2018 to 2019.
Methodology: Water was sampled from down, middle and upstream of River Nyamwamba and River Mubuku, Western Uganda (as a control) during the wet and 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 R. Nyamwamba.
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. There was an extremely high concentration of HMs in the upstream sample than expected. Health risk assessment indicated that the EDI through dermal contact ranged from 0.015 mg/kg/day to 4.150 mg/kg/day while through ingestion of contaminated water, the values ranged from 0.008×10^{-6} mg/L/day to 38.266×10^{-6} mg/L/day. 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 R. Nyamwamba. 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 done sporadically 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 is one of the major water resources used around Kilembe copper mine 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 River Nyamwamba (R. Nyamwamba). Farmers cultivating near R. Nyamwamba experience crop wilting whenever the river banks burst, resulting in disastrous floods streaming in the low lands through the incised gorges, valleys and the vast Nyamwamba valley [24-26]. Sand miners attested that mining in R. Nyamwamba has been accompanied by body irritations and itching. Others also hold that drinking water from R. Nyamwamba resulted in abdominal complications in infants. Other reports cited that the pollution of R. Nyamwamba equally impacts the Lake George basin, a Ramsar site [18, 24]. Against the proposition that water from River Mubuku in the same district is uncontaminated when compared to R. Nyamwamba, this study investigated the seasonal variations in HMs content of water from R. Nyamwamba, Western Uganda during the dry season and wet season (after floods), and estimated the health risks associated with use of water from it.

2. MATERIAL AND METHODS

2.1 Description of the study area

River Nyamwamba (**Figure 1**) is a water resource that is fed by melting glaciers originating from the mountains of the moon (the Rwenzori Montane region). An estimated 126 km is stretched by the river and its tributaries, pouring into Lake George [27]. River Nyamwamba 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 R. Nyamwamba in the peak areas of the Rwenzori Mountains [28-30]. River Nyamwamba 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]. R. Nyamwamba is located in the propinquity of the now inactive Kilembe copper mine in Kasese district, Western Uganda.

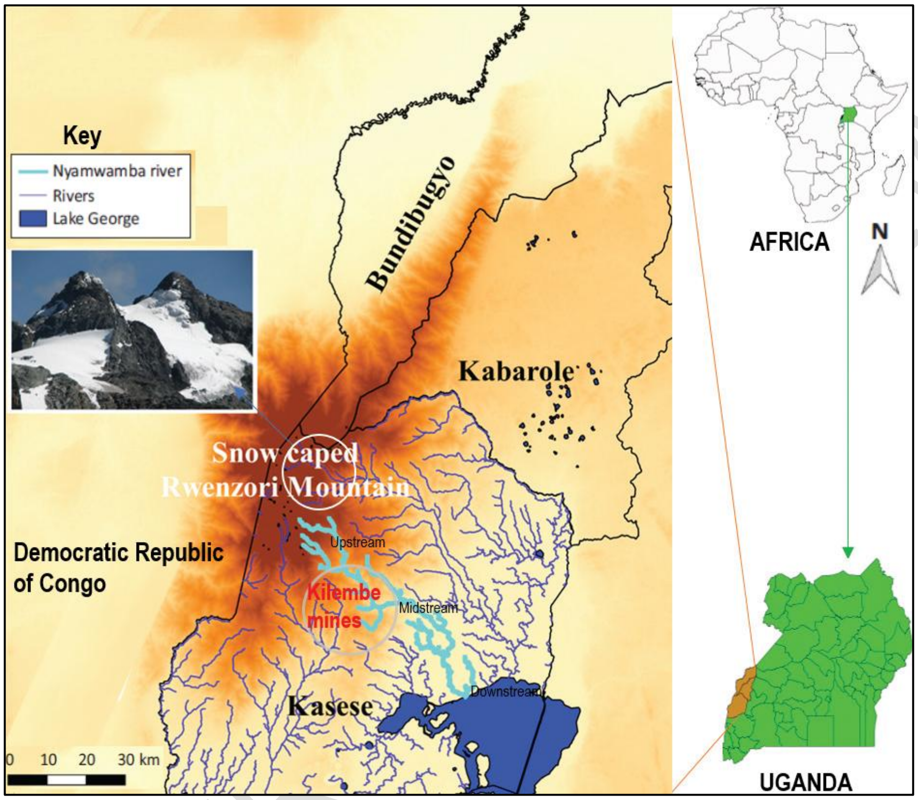

Fig. 1. Map showing the location of River Nyamwamba and Kilembe copper mine in Kasese district, Uganda. Inset is the location of Uganda in Africa and the study area in Uganda. Adapted from Bwambale et al. [27].

2.2 Sampling and sample preparation

Water was purposively sampled from R. Nyamwamba and River Mubuku (as a control) into 500 ml polypropylene bottles. 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 ℃ until commencement of analysis.

2.3 Sample analyses

Non-conservable parameters of the samples such as electrical conductivity, total dissolved solids, 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 and turbidity) 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.

2.4 Human health risk assessment

2.4.1 Estimated daily intake and target hazard quotient

The average daily doses (mg/kg/day and mg/L/day) were computed for children (as a sensitive group) and adults (as the general population) to discern human exposure through direct ingestion ($\mathrm{ADD}_{\mathrm{ing}}$) and dermal contact ($\mathrm{ADD}_{\mathrm{derm}}$) 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].

$$\mathrm{ADD}_{ing} = \frac{C_m \times W_{ir} \times E_f \times E_d}{W_{ab} \times T_{aet}} \qquad (1)$$

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

Wherein 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.

$$\mathrm{THQ} = \frac{ADD_{ing}}{R_f Do} \quad \text{or } \mathrm{THQ} = \frac{ADD_{therm}}{R_f Dd} \qquad (3)$$

$$\text{Total THQ} = \sum_{i=1}^{n} THQ \qquad (4)$$

Where $R_f D_o$ is the oral reference dose while $R_f D_d$ 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 ($R_f Do$ or $R_f Dd$), 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].

$$CR = ADD_{ing} \times CSF \qquad (5)$$

$$TCR = \sum_{i=1}^{n} CR \qquad (6)$$

The CSF (mg/kg/day) 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 was 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 R. Nyamwamba

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 River Mobuku. 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 R. Nyamwamba [19, 44], Mohokare River of Lesotho [45], Nyabugogo and Nyabarongo rivers, Rwanda [42], River Aturukuku [46], River Nyamugasani [47] and River Rwimi 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 R. Nyamwamba and River Mubuku 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 R. Nyamwamba 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 R. Nyamwamba. 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, Mobuku, 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 River Musamya 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 River Rido 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.

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	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.

The mean concentrations of HMs of the analyzed water samples from R. Nyamwamba 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 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 R. Nyamwamba [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. With the exception of Fe, all the HMs surpassed the WHO guidelines for drinking water in the wet season. In the dry season, Cu and Fe 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 R. Mubuku 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 R. Nyamwamba (**Table 2)**.

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, Young [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 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 R. Nyamwamba 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 daily dose through dermal contact ranged from 0.015 mg/kg/day to 4.150 mg/kg/day while through ingestion of contaminated water, the values ranged from 0.008 × 10^{-6} mg/L/day to 38.266 × 10^{-6} mg/L/day (**Table 3**). Some of the calculated daily doses were higher than the corresponding reference doses for ingestion and contact, thus some non-carcinogenic health risks can result from contact and consumption of water from the sampled stations of R. Nyamwamba.

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

Period	Group	Metal	ADD_{ing} (mg/kg/day)			Oral reference dose (mg/kg/day)	ADD_{derm} ($\times 10^{-6}$ mg/L/day)			Dermal reference dose (mg/L/day)
			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].

On the other hand, the target hazard indices through ingestuion 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 × 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 indicate that there potential non-carcinogenic and carcinogenic health risks from consumption and coming into contact with water from R. Nyamwamba which is in agreement with the anecdoctal reports in the area [24, 25].

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

Period	Group	Metal	THQ $_{ing}$			THQ $_{derm}$ (× 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.

For carcinogenic health risks (**Table 5**), the cancer 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. Thus, there are carcinogenic health risks for both adults and children through ingestion of water from R. Nyamwamba.

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

4. CONCLUSION

This study has revealed that water in the whole stretch of R. Nyamwamba is contaminated with heavy metals. Iron occurred in the highest concentration, and the contamination levels of the river are significantly higher during the wet season than the dry season. 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. 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.

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