

Original Research Article

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

ABSTRACT

Aim: In Kasese district of Western Uganda, farmers cultivating near ~~River~~ Nyamwamba ~~River (R. Nyamwamba)~~ experience crop wilting whenever the river banks burst. ~~An~~ 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~~ ~~River~~ 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 physico-chemical parameters and heavy metals (HMs) content of water from ~~R. Nyamwamba~~ ~~River~~, 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: ~~This study employed quantitative research design.~~ Water was sampled from ~~upstream to down, middle and upstream~~ of ~~River~~ Nyamwamba and ~~River~~ Mubuku ~~rivers~~, Western Uganda (as a control) during the ~~dry and wet and~~ seasons. The samples were analyzed for physicochemical parameters (pH, conductivity, total dissolved solids, total suspended solids) 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 hazard 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~~ ~~River~~.

Results: Most physico-chemical 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^{-5} 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 (~~Target Hazard Quotient~~) 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~~ ~~River~~. 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.

Comment [A1]: To include units [mg/L; µS/cm etc.]

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 bio-accumulative 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 River](#)) which have been investigated and reported to be potentially contaminated with HMs [17-19].

In Uganda, [River-Nyamwamba River](#) 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 River\(R-Nyamwamba\)](#). Farmers cultivating near [R-Nyamwamba River](#) 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 River](#) has been accompanied by body irritations and itching. Others also hold that drinking water from [R-Nyamwamba River](#) resulted in abdominal complications in infants. Other reports cited that the pollution of [R-Nyamwamba River](#) equally impacts the Lake George basin, a Ramsar site [18, 24]. Against the proposition that water from [River-Mubuku River](#) in the same district is uncontaminated when compared to [R-Nyamwamba River](#), this study investigated the seasonal variations in HMs content of water from [R-Nyamwamba River](#), Western Uganda during the dry season and wet season (after floods), and estimated the health risks associated with use of water from it.

Comment [A2]: To standard nomenclature

2. MATERIAL AND METHODS

2.1 Description of the Study area

[River-Nyamwamba River](#) (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.

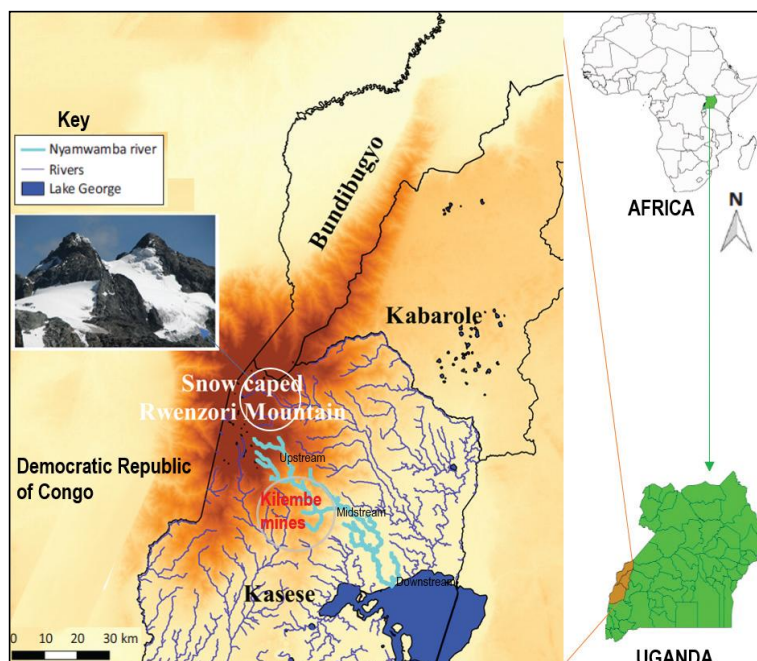


Fig. 1. Map showing the location of River Nyamwamba River and Kilembe copper mine in Kasese district, Uganda. Inset is the location of Uganda in Africa and the study area in Uganda. Adapted from Bwambale et al. [27].

Comment [A3]: To include coordinates [Lat and Long]

2.2 Sampling and sample preparation

Water was purposively sampled from R. Nyamwamba River and River Mubuku River (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 °C until commencement of analysis.

Comment [A4]: Format – Paragraph

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 solids and turbidity) of the samples collected were analyzed in the laboratory.

Comment [A5]: To include units (µS/cm; mg/L etc.)

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.

Comment [A6]: Units from IS

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 (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].

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

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

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 cm² for children and 24,350 cm² 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/cm²/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, $THQ \leq 1$ 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.

$$THQ = \frac{ADD_{ing}}{R_f D_o} \quad \text{or} \quad THQ = \frac{ADD_{therm}}{R_f D_d} \quad (3)$$

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

Where RfD_o is the oral reference dose while RfD_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 (RfD_o or RfD_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.

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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].

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

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

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 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 physico-chemical 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-Muebuku 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 ~~R. Nyamwamba River~~ [19, 44], Mohokare River of Lesotho [45], Nyabugogo and Nyabarongo rivers, Rwanda [42], ~~River-Aturukuku River~~ [46], ~~River Nyamugasani River~~ [47] and ~~River-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 R. Nyamwamba and ~~River-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].

Comment [A7]: Mubuku or Mubuku?

Comment [A8]: Is normal pH > 8 in natural waters from Nyamwamba River?

The other parameters measured only met WHO guidelines for drinking water in the upstream. Conductivity for example ranged from 37.9 to 1500 μ S/cm. There were significant differences in the conductivities of water from ~~R. Nyamwamba River~~ during the dry and wet seasons ($P < 0.05$). Bakyayita et al. [19] and Mwongyera et al. [44] reported conductivity

values of 127 $\mu\text{S}/\text{cm}$ and 104 $\mu\text{S}/\text{cm}$ for water from R. Nyamwamba. The conductivity values recorded are in ranges of 12 to 946.08 $\mu\text{S}/\text{cm}$ for water sampled from rivers: Lubigi, Nyamugasani, Sio, Rwimi, Victoria Nile, Mobuku, Lhubirha, Rwimi and Nyamwamba rivers in Uganda [47, 50]. Similar high conductivity values (108-1524 $\mu\text{S}/\text{cm}$) 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 $\mu\text{S}/\text{cm}$ were recorded [42]. Another investigation in Mohokare River-water, Lesotho [45] reported conductivity of 2000-3800 $\mu\text{S}/\text{cm}$, which are far higher than obtained in this study. In Nigeria, Butu et al. [52] found conductivity of River-Rido River to range from 79 to 146.3 $\mu\text{S}/\text{cm}$, 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 (control)	WHO guidelines
		Downstream (George)	(L. Midstream	Upstream		
Wet season	pH	6.75	6.44	7.20	6.54	6.5-8.5
	Conductivity ($\mu\text{S}/\text{cm}$)	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
	pH	6.70	6.51	6.87	6.80	6.5-8.5
	Conductivity ($\mu\text{S}/\text{cm}$)	1100	1500	400	150	1000
Dry season	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 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 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 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], Bakayita 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	Bakayita 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]
River Rwimi (Uganda)	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 Mubuku (Uganda)	ND	0.010	0.067	0.01	ND	ND	ND	
Nyabarongo river (Rwanda)	ND	0.025	0.053	0.01	ND	ND	ND	This study
	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	
	0.63-1.61	BDL-0.24	0.05-0.75	BDL-0.09	BDL-0.06	BDL-0.106	ND	
Nyabugogo river (Rwanda)	1.57	0.29	0.59	0.43	0.15	BDL	ND	Omara et al. [42]; Nteziyaremye and Omara [11]
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 Marengue 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 (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 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 physico-chemical 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 River.

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

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 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 indicated 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 anecdotal 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 potential 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 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.

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.

Comment [A9]: To use MS Word Template and Latex Template for manuscript structure; reference style and nomenclature and units.

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