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Health Risk Assessment of Heavy Metals in the Water of the Loutété River, Mfouati District, Southeast Congo

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Abstract

The overall objective of this study was to assess the health risk of water in the Loutété River contaminated with heavy metals. Six surface water samples were collected during the dry season (October 2014). The physico-chemical parameters (pH, electrical conductivity, total dissolved salts) were measured using a HANNA brand device. The values of these physico-chemical parameters are below the WHO standards. The concentrations of heavy metals Cr, Cu, Fe, Pb, Zn and Mn were determined by ICP-OES. These obtained in (µg/L) are in the range: Cr (0.08 - 5.8); Cu (0.6 - 14.5); Fe (0.2 - 386.05); Pb (1.02 - 370.09); Zn (8.02 - 248.7) and Mn (37.1 - 328.08). These concentrations are below the WHO drinking water guideline value in all samples for Cr, Cu, Mn and Zn, 50, 2000, 400 and 3000 µg/L respectively. Concentrations of As, Fe and Pb exceeded the WHO guideline value for drinking water at the following stations: S1 for arsenic, S4 for iron, and for Pb at all stations except S5. The health risk assessment for adults due to ingestion exposure gave HQing. values < 1 for the following heavy metals: Cr, Cu, Fe, Mn, Zn, except for Arsenic and Lead. The hazard quotient calculated by dermal contact (HQ derm) in the waters of the river Loutété, showed that HQ derm < 1 for all heavy metals in all stations. For children, the dermal contact hazard quotient HQ derm < 1 for all heavy metals As, Fe, Cu, Zn, Mn, Cr and Pb. With the exception of station S4, we observed that HQ > 1 for lead. In the case of ingestion, HQing. < 1 for the heavy metals Cr, Cu, Zn, Mn, with the exception of the following metals Arsenic, Lead and Iron.

Keywords

Hazard Quotient, Non-Carcinogenic Risk, Heavy Metals

1. Introduction

Water is an indispensable element in everyday life and its use in different areas of life depends on its physical and chemical properties. Water can be contaminated by heavy metals, these metals in drinking water can come from various sources such as natural sources, urbanization, industrialization, agricultural runoff, mining activity and traffic emissions (Li & Wu, 2019; Zhang et al., 2019; Nkpaa et al., 2018; Cobbina et al., 2015). Mining activity is the major source of heavy metal pollution in waters. These are delivered to rivers, streams, lakes, estuaries, and lagoons through runoff (Wang et al., 2008; Audry et al., 2010; Korça & Demaku, 2020; Negahban et al., 2020). The phenomenon of water runoff results in increased concentrations of heavy metals in water, which in turn will pose a risk to human health (Wang et al., 2008). The health risk has been assessed by the US Environmental Protection Agency (USEPA, 1989) which shows that humans can be exposed to heavy metals by ingestion (mouth) and skin contact (Wang et al., 2008; Audry et al., 2010; Fu et al., 2009; Li et al., 2009; USEPA, 1989). The Loutété River, located in the Bouenza department (southern Congo Brazzaville), is a tributary of the Niari River. For several years it has been influenced by the activities of a plant processing a polymetallic ore rich in metallic sulfides. Currently this plant is in full abundance. The local population uses this water for agriculture, fishing, washing dishes, cooking tubers, etc. In view of all these activities, the physical-chemical properties and heavy metal contents are not known. It is in this perspective that we propose to know the quality of this water and to evaluate the sanitary risk for health.

2. Materials and Methods

2.1. Study Area

The Loutété River, located between the southern latitude of 367178.59 to 370507.20 UTM and eastern longitude of 9512957.94 to 9515800.06 UTM. This area is characterized by an equatorial climate, a vegetation of savannah type and a soil of ferralitic type. The temperature varies between 25˚C and 36˚C during the rainy season against 18˚C and 24˚C during the dry season. Annual rainfall varies between 1050 and 1650 millimeters (Matini et al., 2011).

Figure 1 below represents selected study area of Mfouati in this study.

2.2. Sampling and Analysis

A sampling campaign was conducted in October 2014 (dry season) during which six stations were selected. In each station, 1L of surface water was taken, stored in a Teflon bottle and acidified with nitric acid. The physico-chemical parameters

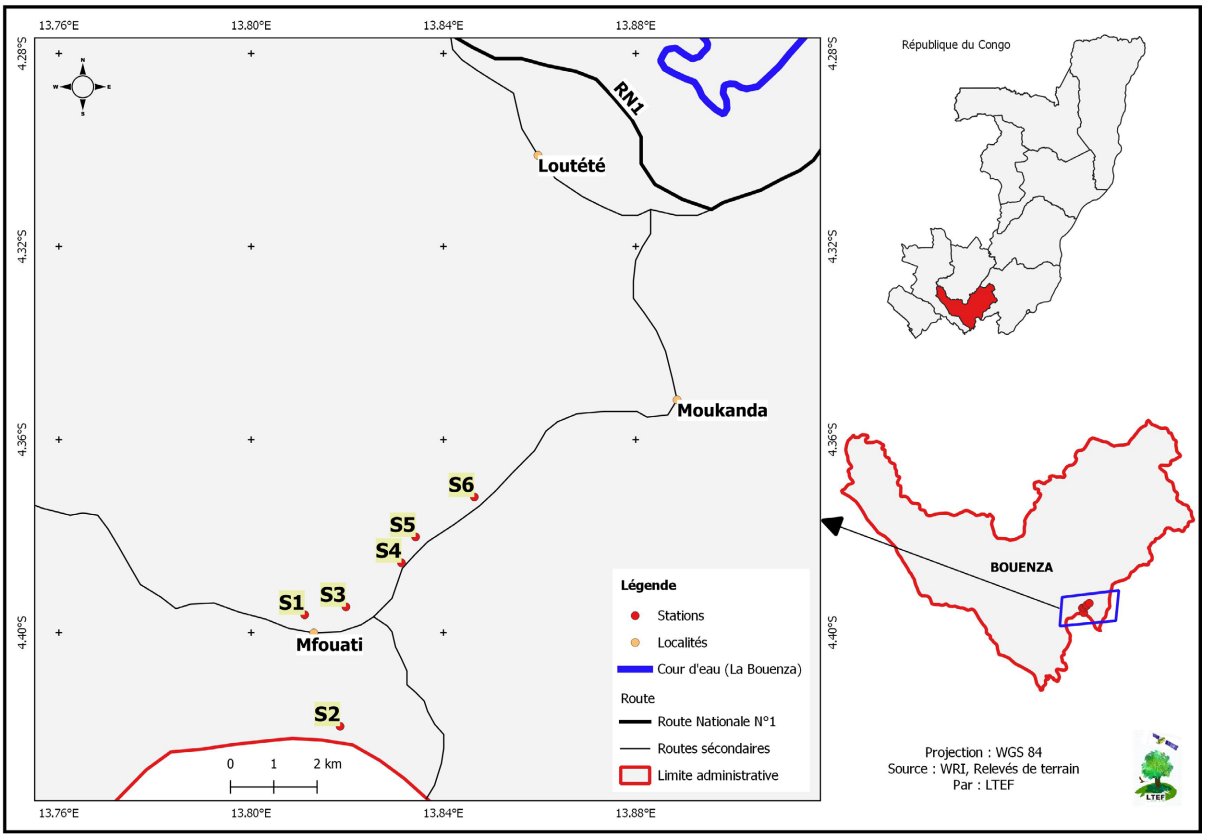

Figure 1. Mfouati study area.

(pH, electrical conductivity, total dissolved salts) were measured on site using a HANNA multi-parameter measuring device. The acidified water was kept in a refrigerator at 4˚C in the laboratory and sent to the black tip analytical laboratory (SGS) to determine the heavy metal content by ICP-OES.

2.3. Exposure Assessment

The Environmental Protection Agency has shown that heavy metals can enter the human body through the mouth, nose and skin. Equations (1) and (2) have been used to estimate exposure doses from mouth and skin contact (Grzetic & Ghariani, 2008; Khan et al., 2008; USEPA, 2011).

$$\text{Exp ing} = \frac{\text{Cw} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (1)$$

$$\text{Exp derm} = \frac{\text{Cw} \times \text{SA} \times \text{Kp} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}} \quad (2)$$

Cw: average concentration of metals in water; IR: ingestion rate; EF: ingestion rate; ED: exposure duration; BW: average body weight; AT: average time; SA: exposed skin area; Kp: skin coefficient of permeability in water; ET: exposure time; CF: unit conversion factor.

Table 1 below represents values of the parameters to calculate the exposure doses by mouth and skin contact

Table 1. Parameters recommended by US. EPA for non-carcinogenic risk assessment of metals (USEPA, 1989).

Parameter	Unit	Adult	Child
IR	L/days	2.2	1.8
EF	Days/year	365	365
ED	Years	60	6
BW	Kg	60	15
AT	days/year	365	6
SA	Cm^2	18	6600
ET	h/day	0.58	1
CF	L/cm^3	0.001	-
Kp	Cm/h		
As		0.002	
Cu		0.001	
Cr		0.002	
Fe		0.001	
Mn		0.001	
Pb		0.004	
Zn		0.0006	

2.3.1. Non-Carcinogenic Risk Index (HQ)

The potential non-carcinogenic risk of exposure to contaminants (HQ) was calculated by the ratio of the exposure doses to contaminants calculated according to the exposure routes (Exp) (ingestion, dermal) to the reference dose (RfD). HQ was calculated by the following equation: to estimate the non-carcinogenic risk, HQ was calculated by the following equation (Khan et al., 2008):

$$\text{HQ ing/Derm} = (\text{Exp ing/Derm})/(\text{rfd ing/Derm}) \quad (3)$$

when HQ less than 1 the risk is considered non-carcinogenic, HQ greater than 1 may be a major potential health concern.

To calculate the hazard quotient for the potential non-cancer risk (HQ), the toxicity reference dose value was used. **Table 2** below gives the values toxicological reference parameters for selected metals (RfD).

2.3.2. Total Risk Index (HI)

Total Risk Index (HI) has been used to assess the risk to human health from exposure to multiple metals. The risk index is the sum of the quotient risk calculated for the entire metal (USEPA, 1989; USEPA, 2011).

$$\text{THI} = \Sigma\text{HQ} = \text{HQPb} + \text{HQMn} + \text{HQFe} + \text{HQCu} + \text{HQZn} + \text{HQCr} \quad (4)$$

when HI > 1, exposure to water can have an adverse effect on human health (Naveedullah et al., 2014).

Table 2. Toxicological reference parameters for selected metals.

Metal	RfD_{ing} (µg/kg/day)	RfD_{derm} (µg/kg/day)
Cr	3	0.075
Cu	40	8
Fe	700	140
Mn	24	0.96
Pb	1.4	0.42
Zn	30	60

3. Results and Discussion

3.1. Physico-Chemical Parameters of the Water of the Loutété River

The results of the physico-chemical parameters are presented in Table 3 below to interpret the physico-chemical properties of the water.

Temperatures vary between 22.4˚C and 25˚C with an average of 23.61. The highest temperature is observed in station six. In all six stations, these temperatures are below the standard established by the WHO (30 - 40). The pH values range from 4.77 to 8.49 with a pH maximum in S4. The values are close to the WHO standard. The TDS values are between 175 and 255. These values are well below the WHO standard (1400).

3.2. Heavy Metals in Water

Table 4 below gives concentrations of heavy metals obtained in the six stations of the river Loutété.

Chromium concentrations range from 0.08 to 5.8 µg/l, with an average of 1.96 µg/l. These concentrations are lower than the WHO standard. The copper concentration varies between 0.6 and 14.5 µg/l, with an average of 5.58 µg/l. The copper concentration is lower than the WHO standard. The Iron concentration varies between 0.2 and 386.05 µg/l, with an average of 122.37 µg/l. Its concentration is lower than the WHO standard. Lead whose concentration varies between 1.02 and 370 µg/l with an average of 103.1 µg/l. The concentration of lead exceeds the admissible limit for lead recommended by the WHO which is 10 µg/l. Zinc whose concentration varies between 8.02 and 248.7 µg/l, with an average of 76.06 µg/l. The concentration is lower in zinc than the WHO standard. Manganese concentration varies between 37.1 and 328.08 µg/l with an average of 162.31 µg/l. The concentration of Manganese is lower than the WHO standard. The low concentrations observed in the surface water are due to the exchange between polluted ores and the surface water. On the other hand low concentrations can be explained by co-precipitation by oxides or absorption on mineral surfaces (Wu et al., 2009). The concentration of arsenic varies between 0.7 and 30 µg/l. The arsenic concentrations exceed the respective guideline value for drinking water (10 µg/L) respectively in the station (S1).

Table 3. Physico-chemical parameters.

Stations	T ˚C	Physico-chemical parameters		
		pH	CE	TDS
S1	24.5	8.15	277.5	175
S2	23.5	8.33	392.94	227
S3	25	4.77	291	205
S4	23.2	8.49	388.5	225
S5	22.4	8.29	397.38	229
S6	22.9	8.14	455.1	255
moy	23.61	7.69	367.07	219.33
E.D	0.98	1.43	68.71	26.93
Min	22.4	4.77	277.5	175
Max	25	8.49	455.1	255
WHO SD	30 - 40	6.5 - 8.5	1000	1400

Table 4. Heavy metal concentration in water (µg/l).

Stations	Cr	Cu	Fe	Pb	Zn	Mn	As
S1	1.14	2	110	108.9	8.02	108.67	30
S2	2.8	14	50	67.6	40.3	70.03	10
S3	1.05	0.6	0.2	1.02	49.2	130	2.28
S4	0.08	14.5	386.05	370.09	248.7	328.08	1
S5	0.9	0.8	40.07	3.9	50.06	37.1	0.7
S6	5.8	1.6	147.9	67.09	60.08	300	6
Minimum	0.08	0.6	0.2	1.02	8.02	37.1	0.7
Maximum	5.8	14.5	386.05	370.09	248.7	328.08	30
Average	1.96	5.58	122.37	103.1	76.06	162.31	8.33
Median	1.0950	1.8000	80.0000	67.3450	49.6300	119.3350	4.1400
S.D	2.0789	6.7345	139.4763	137.2117	86.4472	122.1086	11.1925
WHO standard	50	2000	300	10	3000	400	10

S.D: Standard deviation.

3.3. Correlation between Heavy Metals in the Waters of the Loutété River

Correlation analysis establishes the relationship between heavy metals in the samples. A high correlation (r = 1, or close to 1) shows a positive association between two metals (Saeedi et al., 2012; Lu et al., 2010). The table below gives us the correlations between the different metals. Correlations exist between: [Zn-Pb] r = 0.89; [Mn-Pb] r = 0.69; [Fe-Pb] r = 0.97; [Zn-Mn] r = 0.71; [Fe-Mn] r = 0.81; [Fe-Zn] r = 0.90. In view of these values we note that these metals taken two by two have the same sources and similar geochemical behavior.

Table 5 below shows correlation between two elements.

3.4. Health Risk Assessment

3.4.1. Non-Carcinogenic Risk Assessment for Dermal Contact with Water

Table 6 below shows the hazard quotient (HQ) results for a potential non-cancer hazard and the cumulative hazard indices (for adults).

The dermal hazard quotient (HQ derm) values calculated for the waters of the Loutété River show that HQ derm is less than 1 for all heavy metals at all stations. This indicates that there is no health risk to the population exposed by dermal contact. The calculated ingestion risk quotient values (ing HQ) for the following heavy metals: Cr, Cu, Fe, Mn, Zn are less than 1 at all stations. Except in the case of Arsenic and lead where we observe (HQ ing) is higher than 1 in the stations S1 for arsenic and S4, S6 for lead. This shows that the metal arsenic

Table 5. Correlation between heavy metals in the water of the river Loutété.

	Cr	Cu	Fe	Pb	Zn	Mn	As
Cr	1.00						
Cu	−0.18	1.00					
Fe	−0.17	**0.57**	1.00				
Pb	−0.33	**0.69**	**0.97**	1.00			
Zn	−0.34	**0.62**	**0.90**	**0.89**	1.00		
Mn	0.27	0.27	**0.81**	**0.69**	**0.71**	1.00	
As	0.02	−0.14	−0.13	−0.06	−0.50	−0.25	1.00

Table 6. Hazard Quotient (HQ) for a potential non-carcinogenic risk and cumulative hazard indices (for adults).

	As		Cr		Cu		Fe	
Echantillon	HQ ing	HQ derm.	HQ ing	HQ derm.	HQ ing	HQ derm.	HQ ing	HQ derm.
S1	3.14E+00	2.44E−06	1.19E−02	4.53E−03	1.57E−03	3.73E−05	4.94E−03	3.73E−05
S2	1.05E+00	8.14E−07	2.93E−02	1.11E−02	1.10E−02	2.61E−04	2.24E−03	2.61E−04
S3	2.39E−01	1.85E−07	1.10E−02	4.18E−03	4.71E−04	1.12E−05	8.98E−06	1.12E−05
S4	1.05E−01	8.14E−08	8.38E−04	3.18E−04	1.14E−02	2.70E−04	1.73E−02	2.70E−04
S5	7.33E−02	5.70E−08	9.43E−03	3.58E−03	6.29E−04	1.49E−05	1.80E−03	1.49E−05
S6	6.29E−01	4.88E−07	6.08E−02	2.31E−02	1.26E−03	2.98E−05	6.64E−03	2.98E−05
Moyenne	8.73E−01	6.79E−07	2.06E−02	7.80E−03	4.39E−03	1.04E−04	5.49E−03	1.30E−04
	Mn		Pb		Zn			
Echantillon	HQ ing	HQ derm	HQ in	HQ derm	HQ ing	HQ derm	HI ing	HI derm
S1	1.42E−01	1.69E−02	5.43E−01	1.69E−02	8.40E−03	1.19E−05	5.76E+00	1.76E−01
S2	9.17E−02	1.09E−02	3.50E−01	1.09E−02	4.22E−02	6.01E−05	2.74E+00	1.18E−01
S3	1.70E−01	2.02E−02	6.50E−01	2.02E−02	5.15E−02	7.33E−05	4.95E−01	2.59E−02
S4	4.30E−01	5.10E−02	1.64E+00	5.10E−02	2.61E−01	0.00037	9.13E+00	5.78E−01
S5	4.86E−02	5.76E−03	1.86E−01	5.76E−03	5.24E−02	7.46E−05	2.74E−01	1.50E−02
S6	3.93E−01	4.66E−02	1.50E+00	4.66E−02	6.29E−02	8.96E−05	2.66E+00	1.65E−01
Moyenne	2.13E−01	2.52E−02	2.31E+00	1.46E−01	7.97E−02	1.13E−04	**3.51E+00**	**1.80E−01**

Table 7. Hazard Quotient (HQ) for potential non-carcinogenic risk and cumulative hazard indices for children.

	As		Cr		Cu		Fe	
Echantillon	HQ ing	HQ derm.	HQ ing	HQ derm.	HQ ing	HQ derm.	HQ ing	HQ derm.
S1	1.20E+00	7.21E−06	4.56E−02	1.34E−02	1.57E−03	1.10E−04	9.33E+00	3.46E−04
S2	4.00E−01	2.40E−06	1.12E−01	3.29E−02	1.10E−02	7.70E−04	5.79E+00	1.57E−04
S3	9.12E−02	5.48E−07	4.20E−02	1.23E−02	4.71E−04	3.30E−05	8.74E−02	6.29E−07
S4	4.00E−02	2.40E−07	3.20E−03	9.39E−04	1.14E−02	7.98E−04	3.17E+01	1.21E−03
S5	2.80E−02	1.68E−07	3.60E−02	1.06E−02	6.29E−04	4.40E−05	3.34E−01	1.26E−04
S6	2.40E−01	1.44E−06	2.32E−01	6.81E−02	1.26E−03	8.80E−05	5.75E+00	4.65E−04
Moyenne	3.33E−01	2.00E−06	7.85E−02	2.30E−02	4.39E−03	3.07E−04	8.84E+00	3.85E−04
	Mn		Pb		Zn			
Echantillon	HQ ing	HQ derm	HQ in	HQ derm	HQ ing	HQ derm	HI ing	HI derm
S1	3.21E−02	4.98E−02	5.43E−01	4.56E−01	8.40E−03	2.05E−04	1.12E+01	5.20E−01
S2	1.61E−01	3.21E−02	3.50E−01	2.83E−01	4.22E−02	1.03E−03	6.87E+00	3.50E−01
S3	1.97E−01	5.96E−02	6.50E−01	4.27E−03	5.15E−02	1.26E−03	1.07E+00	7.75E−02
S4	9.95E−01	1.50E−01	1.64E+00	1.55E+00	2.61E−01	6.35E−03	3.45E+01	1.71E+00
S5	2.00E−01	1.70E−02	1.86E−01	1.63E−02	5.24E−02	1.28E−03	7.93E−01	4.54E−02
S6	2.40E−01	1.38E−01	1.50E+00	2.81E−01	6.29E−02	1.53E−03	7.99E+00	4.89E−01
Moyenne	3.04E−01	7.44E−02	8.12E−01	4.32E−01	7.97E−02	1.94E−03	**1.04E+01**	**5.32E−01**

and lead can cause adverse effects by ingestion of water for the population. Considering the mean value, HI ing > 1. This indicates that there is an adverse effect on the health of the population. The average of HI derm < 1. This indicates that there is no adverse effect on the health of the population.

3.4.2. Non-Carcinogenic Risk Assessment for Children

Table 7 shows the hazard quotient (HQ) results for a potential non-cancer hazard and the cumulative hazard indices (for children).

The dermal HQ values calculated by dermal contact for all heavy metals As, Fe, Cu, Zn, Mn, Cr and Pb for children are lower than 1 in all six stations. The risk is observed when HQ is greater than or equal to 1. In our case, in station S4 we observe that HQ > 1 for lead. This shows that lead is dangerous for populations exposed by dermal contact. In the case of ingestion, the heavy metals Cr, Cu, Zn, Mn do not pose any risk to the population because the value of the risk quotient HQ lower than 1 in all stations. The following metals Arsenic, Lead and Iron pose a risk problem in the following stations: S1, S2 for arsenic; S4, S6 for Lead; and S1, S2, S4, S6 for Iron. The average HI ing > 1 and the average HI derm < 1 as observed previously in the adult case. This brings us to the same conclusion.

4. Conclusion

The general objective of this study was to evaluate the health risk of populations

exposed to heavy metals by ingestion and skin contact. The concentrations of heavy metals (Pb, As, Cu, Zn, Cr, Fe, Mn) were determined by ICP-OES. The health risk was estimated by dermal contact and ingestion. The physico-chemical parameters were measured using a HANNA multi-parameter. Regarding the results of heavy metals in water, the concentrations of heavy metals in water are lower than the standard of the O.M.S. The risk on health in the case of the adult the average of HI ing > 1. This leads to adverse health effects. The average HI derm < 1. This means that there are no significant adverse health effects. In the case of children, the average HI ing > 1 and the average HI derm < 1 as observed previously in the case of adults. This brings us to the same conclusion as in the case of the adult. The chemical composition of the river water is characterized by an alkaline pH with the exception of station S4. The pH values range from 4.77 (S4) to 8.49 (S5). These measured values respect the WHO standards for water (6.5 < pH < 9.5). The electrical conductivity measured in these waters is between 278 µS/cm (S1) and 455 µS/cm (S6), these values are lower than the WHO standard (1000 µS/cm). The values of total dissolved salts (TDS) in the water are between 175 and 255. These values are lower than the WHO standard (1400).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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