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Kafubu River Fish, Real Poisons for the Consumer Population in the South East of the Democratic Republic of Congo

Mawazo Kaya Koya[1], Mbuba Justin Kalunga[2], Mugimba Dieudonné Kitenge[3] and Lwamba Joseph Lulu[4]

1. School of Public Health, University of Kalemie, Kalemie, DR Congo

2. Health Sciences Department, University of Kalemie, Kalemie, DR Congo

3. Technological Sciences Department, University of Kalemie, Kalemie, DR Congo

4. Agricultural Sciences and Environment Department, University of Kalemie, Kalemie, DR Congo

Abstract: In the Democratic Republic of Congo, the Kafubu River has received, for several decades, mining waste from GECAMINE Kipushi and Lubumbashi as well as those from the CHEMAF plant. Given this situation, we wanted to verify the degree of contamination of fish in the Kafubu River with TME (Trace Metal Elements). In doing so, fish samples from this river, downstream of mining activities, as well as samples of reference fish from upstream of any mining activity from the sources of the Panda and Kasungwe rivers and that of the Congo River were analyzed with Inductively Couple Plasma Mass Spectrometry (ICP-MS) and Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES). Statistical analysis, using the Wilcoxon test, of the results obtained as well as the comparison of these with the thresholds of the WHO (World Health Organization), FAO (Food and Agriculture Organization) and the EU (European Union) revealed that the fish of the Kafubu River are contaminated with As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn. Thus, it was concluded that the fish of the Kafubu River were not fit for human consumption. In addition, because of the very high level of bioaccumulation of these TMEs in the fish of the Kafubu River, the latter have been described as poisonous for the consuming population. The main principle that emerges from this study is that fish from an ecosystem polluted by mining waste are not fit for human consumption. The results of this study will be brought to the attention of Decision- makers in the Haut-Katanga Province so that rigorous measures can be taken to prohibit metallurgical plants from dumping their mining waste into aquatic ecosystems.

Key words: Fish, Kafubu River, poison, TME, bioaccumulation, South Eastern of DR Congo.

1. Introduction

The Kafubu River in the Republic of Congo has been receiving mining wastes for several decades from the FEL (Lubumbashi Electric Foundry), which belongs to the large mining company GECAMINES (The General of Quarries and Mines) and produces a slag containing mainly Cu, Co, Cd and Ge [1]. We observed that this slag is stored a few meters from the Lubumbashi River and during the rains a certain quantity of these discharges flow into the Lubumbashi River, which flows into the Kafubu River. The Kafubu River has been receiving discharges from the New Kipushi Concentrator located 30 km from Lubumbashi for over seven decades. Chemical analysis of the discharges revealed that they contained As (740 mg/kg), Cd (110 mg/kg), Cu (3,600 mg/kg), Co (428.57 mg/kg), Mn (553.93 mg/kg), Pb (200 mg/kg), and Zn (with 15,000 mg/kg). And finally, the Kafubu River has been receiving, since 2005, mining wastes from the CHEMAF (Chemicals of Africa) plant through the waters of the Kanaviundu River, which contains at very high concentrations, and above their threshold, Al (1,644.95 µg/L), Co (428.57 µg/L), Cu (826.17 µg/L), Mn (553.93 µg/L), Pb (42.52

Corresponding author: Mawazo Kaya Koya, Ph.D., Associate Professor, Research fields: environmental toxicology and health safety of fish.

μg/L) and also contains other TME (Trace Metal Elements) such as As, Cd, Ni and U [2, 3].

However, the Kafubu River is very rich in fish that it provides to the riverside population, including in the city of Lubumbashi that this river crosses. It can therefore be said that the fish of the Kafubu River bathe in an aquatic environment polluted by mining wastes containing TMEs.

Food remains, for humans, the main source of TME contamination [4]. This is why monitoring the quality of fish and its aquatic environment, in accordance with the recommendations of Decree No 038/2003 of March 8, 2003 [5] relating to the Mining Regulation in its article 462, is of great importance for the protection and preservation of the health of the population who regularly consume, in our country, fish from rivers polluted by mining waste such as the Kafubu River.

Despite the fact that the Congolese population of the South-East of the Democratic Republic of Congo consumes fish from aquatic ecosystems polluted by mining wastes, which are otherwise untreated, studies on the quality fish are rare in our country and almost non-existent during the last 13 years. Indeed, apart from our work on the quality of fish, particularly that of Lake Tshangalele in 2012 and 2017, Katemo et al. [6] studied the impact of mining effluents from the Shituru Hydrometallurgical Complex on the Lufira basin. The results showed that there was significant contamination in TMEs, particularly in the gills of *Oreocromis macrochir* fish in Pb (0.95 mg/kg), Co (93.17 mg/kg) and Cu (55.8 mg/kg) and *Tilapia rendalli* in Pb (0.60 mg/kg), Co (48.3 mg/kg) and Cu (33.2 mg/kg).

We believe that the fish of the Kafubu River is contaminated, particularly in TMEs that must be determined in this study. From the chemical quality of the samples, we will be able to say whether the fish from the Kafubu River are safe and therefore fit for human consumption or not. Thus, the objective of this study is to assess the safety of fish from the Kafubu River.

2. Material and Method

2.1. Study Environment

The Kafubu River, the Panda and Kasungwe Rivers as well as the source of the Congo River constituted the main research environment. All these aquatic ecosystems are located in the Haut-Katanga province in the south east of the DR Congo. The Kafubu River has its source in the Kipushi territory. It crosses the south east of the city of Lubumbashi from west to east and bathes the Kalebuka district of this city as well as the localities of Kamilombe, Sambwa and Kikula. Further on, it flows into the Luapula River which itself flows into Lake Moero. The Luapula River forms the border between the Democratic Republic of Congo and the Republic of Zambia.

2.2 Fish Studied

The fish studied belong to different families and species: Cyclidae (*Pseudocrenilabus philander* and *Coptodon rendalli*, *T. sparrmanii*), Claridae (*Clarias buthupogon*, *C. dumerlii*), Mochokidae (*Synodontis* sp.), Cyprinidae (*Enteromius neefi*, *E. miolepis*), Cyprinodontidae (*Lacustricola katangae*), Anabantidae (*Ctenopoma multispine*).

2.3 Material

From September to October 2015, fish samples from the Kafubu River were collected, downstream of the mining activities, at the site of Kamilombe (n = 23) located 17 km from the city of Lubumbashi. Reference fish samples were collected upstream of any mining, industrial or artisanal activity, at the sections located near the sources of the Panda and Kasungwe rivers and the Congo River (n = 11). The fish were caught by net at the Kamilombe site. After collection, each fish sample was packed in a 0.5 $\times$0.5 cm bag, well labeled and well coded: the date of collection, the name of the river of origin, the capture site and a serial number were clearly indicated.

All fish samples were transported in an isothermal box. Upon arrival, all fish samples were placed and stored in a freezer while awaiting preparation and transport to the laboratory. Preparation consisted first of stripping each fish sample of its viscera and scales, then cleaning them with distilled water. Then, for drying, each sample was placed in a petri dish and introduced into a Binder brand oven for 48 h and at 70 ℃. After drying, each sample was crushed separately and made into powder using a mortar and a small porcelain pestle, then well packed in a 28 × 17 cm bag. Finally, all the samples were sent to the laboratory for metal determination.

2.4 Methodology

Ten TMEs namely Al, As, Cd, Cu, Co, Mn, Ni, Pb, Se and Zn had been chosen to be determined in the fish samples. They were analyzed with Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES) at the OCC (Congolese Control Office) in Lubumbashi in the DR Congo and Inductively Couple Plasma Mass Spectrometry (ICP-MS) at the laboratory of the Catholic University of Leuven in Belgium.

2.5 Statistical Analysis of Results

The concentrations of fish samples from the Kafubu River were compared with the concentrations of reference fish samples from the Panda and Kasungwe Rivers as well as the source of the Congo River, using the Wilcoxon test as described by Ancelle [7]. In addition, the concentrations of fish samples from the Kafubu River were compared with the WHO (World Health Organization), FAO (Food and Agriculture Organization) and EU (European Union) thresholds as reported by Akoto et al. [8].

3. Results

Table 1 shows that the concentrations are quite low. In fact, no concentration was found to be higher than the thresholds established by the WHO (30 mg/kg for Cu and 2 mg/kg for Cd and Pb).

Table 1 Concentrations of trace metallurgical elements in the reference fish samples taken from the sources of the Kasungwe, the Panda and The Congo Rivers (mg/kg).

No.	Codification	Scientific name	Al	As	Cd	Co	Cu	Mn	Ni	Pb	Se	U	Zn
1	LUAS P22	*Enteromius neefi*	98.90	0.06	0.20	0.22	2.98	34.40	0.57	0.29	0.78	0.0	691.30
2	LUAS P23	Not identified	292.70	0.14	0.43	0.62	5.40	24.72	0.43	0.59	0.85	0.02	205.80
3	LUAS P24	Not identified	350.20	0.14	0.43	1.01	4.64	30.20	0.62	0.15	0.79	0.02	196.0
4	LUAS P25	Not identified	307.70	0.11	0.24	0.45	3.84	22.41	0.62	0.17	0.82	0.02	184.50
		Average	262.37	0.11	0.32	0.57	4.22	27.93	0.56	0.30	0.81	0.01	319.4
		Standard deviation	111.7	0.0	0.1	0.3	1.0	5.4	0.1	0.2	0.0	0.0	248.1
5	KAS P27	*Clarias dumerlii*	166.8	0.17	0.02	0.11	1.91	8.42	0.30	0.14	2.1	0.01	29.2
6	KAS P28	*Clarias dumerlii*	130.8	0.205	0.02	0.11	1.53	8.88	0.20	0.22	2.04	0.0	26.9
		Average	148.8	0.2	0.02	0.11	1.72	8.65	0.25	0.18	2.07	0.0	28.05
		Standard deviation	2	0.0	0.0	0.0	0.3	0.3	0.1	0.1	0.0	0.0	1.6
7	PAS P29	*Clarias dumerlii*	27.5	0.25	0.06	0.17	2.86	14.8	0.29	0.41	2.76	0.01	47.5
8	PAS P30	*Ctenopoma multispine*	36.4	0.08	0.13	0.29	1.92	14.23	0.15	0.03	2.19	0.0	44
9	PAS P33	*Synodontis* sp.	28.3	0.07	0.3	0.34	1.72	16.15	0.11	0.05	1.83	0.0	58.1
10	PAS P34	*Synodontis* sp.	31.2	0.04	0.26	1.09	1.58	13	0.14	0.07	2.06	0.0	41.9
11	PAS P36	*Lacustricola katangae*	73.1	0.0 3	0.1	0.07	1.87	17.41	0.18	0.05	1.53	0.01	126.7
		Average	39.3	0.11	0.17	0.39	1.99	15.12	0.17	0.12	2.07	0.0	63.64
		Standard deviation	19.2	0.1	0.1	0.4	0.5	1.7	0.1	0.2	0.5	0.0	35.8
General average			162.8	0.2	0.18	0.41	2.75	18.6	0.33	0.2	1.6	0.01	150.2
General standard deviation			122.5	0.1	0.1	0.4	1.3	8.4	0.2	0.2	0.7	0.1	192.8

Table 2 Concentrations of ETM in fish samples taken from the Kafubu at the Kamilombe site (mg/kg).

No.	Codification	Scientific name	Al	As	Cd	Co	Cu	Mn	Ni	Pb	Se	Zn
1	KAMIL P13	*Clarias buthupogon*	34.13	< 0.002	2.23	4.27	14.69	88.16	5.09	24.71	9.62	112.0
2	KAMIL P14	*Pseudocrenilabrus philander*	835.90	3.673	8.11	53.73	285.70	394.40	6.48	34.68	6.89	289.0
3	KAMIL P15	*Pseudocrenilabrus philander*	383.60	2.047	3.06	27.06	144.70	227.50	4.84	26.21	7.98	167.0
4	KAMIL P16	*Pseudocrenilabrus philander*	735.40	4.057	6.16	38.43	179.60	221.70	5.59	27.99	9.82	224.3
5	KAMIL P17	*Pseudocrenilabrus philander*	261.60	0.07	6.18	34.10	178.70	469.90	4.87	25.29	7.15	288.3
6	KAMIL P18	*Pseudocrenilabrus philander*	2028.0	5.11	12.20	112.90	403.70	837.50	6.3	46.14	6.63	406.0
7	KAMIL P19	*Enteromius miolepis*	154.40	0.10	1.00	10.11	55.55	82.64	7.63	34.78	8.39	163.8
8	KAMIL P19bis	*Enteromius miolepis*	51.06	0.51	1.26	6.08	91.47	59.58	10.96	31.89	7.06	108.4
9	KAMIL P120	*Enteromius miolepis*	74.0	< 0.002	2.29	5.68	47.04	57.28	21.97	154.70	13.66	252.0
10	KAMIL P21	*Enteromius miolepis*	88.24	0.38	2.32	11.60	34.17	237.70	8.77	55.29	1.16	241.0
11	KAMIL P22	*Enteromius miolepis*	104.20	< 0.002	0.79	10.50	30.74	149.2	36.0	48.25	5.59	183.8
12	KAMIL P23	*Enteromius miolepis*	2497.0	< 0.002	1.78	30.77	246.40	397.90	419.4	299.60	97.84	1515.0
13	KAMIL P24	*Enteromius miolepis*	232.30	< 0.002	2.36	25.20	81.76	448.90	52.35	202.60	8.26	268.9
14	KAMIL P25	*Enteromius miolepis*	370.0	0.68	2.56	26.55	60.49	300.30	16.14	39.53	7.43	215.0
15	KAMIL P26	*Enteromius miolepis*	75.27	< 0.002	1.13	10.69	31.71	114.90	22.56	30.90	6.86	161.6
16	KAMIL P27	*Enteromius miolepis*	105.100	< 0.002	1.26	13.10	28.57	142.50	16.20	86.56	6.54	208.1
17	KAMIL P29	*Coptodon rendalli*	514.55	0.79	4.24	28.97	194.90	208.10	9.77	36.25	10.06	182.1
18	KAMIL P30	*Coptodon rendalli*	393.3	1.14	5.68	28.68	175.30	239.50	7.02	40.86	10.59	199.8
19	KAMIL P31	*Coptodon rendalli*	133.50	1.88	10.28	84.31	367.90	524.70	9.24	59.49	9.44	310.4
20	KAMIL P32	*Coptodon rendalli*	450.90	1.77	4.24	35.31	197.20	329.90	6.58	41.62	7.01	206.6
21	KAMIL P33	*Coptodon rendalli*	87.50	< 0.002	0.23	2.62	32.33	40.63	9.61	43.57	8.87	101.6
22	KAMIL P33bis	*Coptodon rendalli*	1026.0	6.21	0.43	5.72	297.60	767.90	24.34	142.20	8.58	340.5
23	KAMIL P34	*Coptodon rendalli*	438.20	< 0.002	< 0.2	34.45	187.10	482.90	25.07	161.8	11.82	248.4
Average			481.5	2.0	3.6	27.86	146.4	296.6	32.03	73.69	12.05	277.9
Standard deviation			626.1	1.9	3.2	26.4	115.4	218.2	85.2	70.7	18.8	279.8

4. Discussion

4.1 Kamilombe site

4.1.1 Al

The comparison by the Wilcoxon test of the Al concentrations of fish samples from the Kafubu River at the Kamilombe site (Table 2) with the Al concentrations of reference fish samples (Table 1) showed that the *z* values are 0.4. This value is lower than 1.96 ($p < 0.05$). There is therefore no significant difference in Al concentrations between fish from the Kafubu River and the reference fish samples. This suggests that there was no Al contamination of fish from the Kafubu River at the Kamilombe site (Table 2).

No physiological role for Al is known in a human or animal organism [9]. In excess in the body, Al is considered neurotoxic and can lead to osteomalacia. In any case, several diseases are associated with exposure to Al [10]. Squadrone et al. [11] obtained lower values for the Lufira River at the Kapolowe-Gare site (135.4 mg/kg) than those obtained in the present study at the Kamilombe (481.5 mg/kg) site.

4.1.2 As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn

Comparison by Wilcoxon test of As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn concentrations of fish samples from Kafubu River at Kamilombe site (Table 2) with As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn concentrations of reference fish samples (Table1) showed that the *z* values are 2.52 for As, 4.5 for Cd, 4.65 for Co, 4.65 for Cu, 4.65 for Mn, 4.65 for Ni, 4.65 for Pb, 4.65 for Se and 2.82 for Zn. All these z values are greater than 1.96 ($p < 0.05$). This means that the ranks of As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn concentrations in the Kafubu River fish samples are higher than the ranks of As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn concentrations in the reference fish samples. Consequently, the Kafubu River fish are to be considered contaminated with As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn.

4.2 Health Status and Safety of Kafubu Fish

We have just noted that the fish of the Kafubu River are contaminated with TMEs. We will now examine two important aspects that will show us to what extent the fish of the Kafubu River have bioaccumulated these MTE, namely the number of contaminating MTE and the state of their bioaccumulation. And we will also talk about the health status of the fish.

4.2.1 The Number of MTE

The number of MTEs that have contaminated the fish of the Kafubu River is impressive. There are nine MTEs at the Kamilombe site (As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn) 16 km from Lubumbashi. It has been shown that exposure to two or more pollutants at the same time, such as MTEs, has additive adverse health effects [8]. Thus, consuming a fish contaminated with Cd only is not the same as consuming a fish contaminated with several MTEs as Cd, Pb, Se and Ni. In the first case, one only risks suffering, for one’s health, the adverse effects that Cd alone can induce. On the other hand, in the second case, consuming a fish contaminated with Cd, Pb, Se and Ni, one risks, for one’s health, suffering all the effects, added together, that all 4 MTEs can induce at the same time. In this case, the fish risks not being like food, but purely and simply constituting a poison for the consumer. A poison or toxic is any substance that, after introduction into the body and depending on the dose, the mode of penetration into the body and the state of the subject, is capable of disrupting certain vital functions and seriously damaging certain organic structures or causing death [12].

4.2.2 State of Bioaccumulation

Among the MTEs that contaminated the fish of the Kafubu River, many of them were highly bioaccumulated. Indeed, when examining the levels of their concentrations, we note the following (Table 2). Cd has 14 concentrations out of 23, or 60.8%, well above the WHO threshold of 2.0 mg/kg. The concentrations vary from 2.23 to 12.2 mg/kg or 1 to 6 times the threshold and 100% of the concentrations are far higher than the EU thresholds (0.02 mg/kg). Cu has 22 concentrations out of 23, which are 95.6% higher than the WHO and FAO threshold of 30 mg/kg. Concentrations range from 30.7 to 403.7 mg/kg, which is 1 to 13 times the WHO/FAO thresholds. However, all concentrations are far higher than the EU thresholds (0.1 mg/kg). Ni has its concentrations 100% higher than the EU threshold of 0.1 mg/kg. Concentrations range from 4.8 to 419.4 mg/kg, which is 4.8 to 4.194 times the EU threshold. Pb has all its concentrations 100% higher than the WHO, EU and FAO thresholds, which are 2.0 mg/kg, 0.3 mg/kg and 0.5 mg/kg respectively. Pb concentrations range from 24.7 to 299.6, which is respectively 12 to 149.8 times the WHO threshold (2.0 mg/kg), 82 to 998 times the EU threshold (0.3 mg/kg) and 49 to 599 times the FAO threshold (0.5 mg/kg). As for Zn, only one Pb concentration (1,515 mg/kg) is higher than the WHO threshold (1,000 mg/kg), but all Pb concentrations are 100% higher than the EU threshold (100 mg/kg).

For Mn, an average of 2.1 mg/kg was considered a reasonable average after experimental work initiated by the CCME (Canadian Council of Ministers of the Environment) [13]. Mn concentrations in fish from the Kafubu River range from 40.6 to 837.5 mg/kg (Table 2), with an average of 296.6 mg/kg. This average is 141.2 times higher than the average of the CCME.

The analysis of MTE concentrations (Cd, Cu, Ni, Pb, Zn, Mn) that we have just done clearly showed how some MTEs were highly bioconcentrated in fish from the Kafubu River.

4.2.3 Bioaccumulation and Food Chains

Note that MTEs accumulate in food chains. On this subject, according to Bliefert and Perraud [14], "metals can reach concentrations several times higher than those found in water or air. This can go further than a plant or animal can no longer serve as food for humans." This is the case for fish in the Kafubu River as it is indicated in Table 3.

When we look closely at Table 3 above, we see how the ETM concentrations in fish have reached levels several powers of 10 (10^n) higher than those found in water. Indeed, here we have n = 6, n = 5, n = 4 and n = 3. We can therefore see that, according to the theory of Bliefert and Perraud [14], the fish of the Kafubu River can therefore be considered as no longer serving as food for the consuming population particularly that of Lubumbashi and Kamilombe, but rather like real poisons.

But, Ouro-Sama et al. [15] obtained, for 3 MTE BCF (Bioconcentration Factor) values much lower than those obtained in this study as indicated in Table 4 below for 4 fish species that we have chosen as examples.

According to the BCF values given in Table 4 above, the BCF values for fish from the Kafubu River are approximately as follow. For As: from 240 (Synodontis schall), 261 (Hemocromis faciatus), 298.5 (Tilapia guineesis) to 390.6 (Tilapia zilii) times higher than the BCF values for fish from the togolese lagoon system; for Cd: from 104 (H. faciatus), 268.7 (T. guineensis), to 283.8 (Synodontis schall and T. zilii); for Pb: from 9,910 (T. zilii), 11,700 (H. faciatus), 13,320 (T. guineensis) to 14,550 (S. schall).

The analysis that has just been done of the levels of MTE concentrations that contaminated the fish of the Kafubu River and their BCF has shown how these MTEs have been highly bioaccumulated. And nothing should surprise us when we know that the pollution of the Kafubu River comes from three sources: the Lubumbashi Electric Foundry, the New Kipushi Concentrator and the CHEMAF metallurgical plant in Lubumbashi. Furthermore, nothing should surprise us when we know

Table 3 Factors of ETM bioaccumulation in fish in the Kafubu River at the Kamilombe site.

No.	MTE	MTE concentrations in fish (mg/kg) (Table 2)	MTE concentrations in water (μg/L) [3]	F_{BC}	Power of 10
1	Mn	296.68 (296680 μg/kg)	< 0.1	> 2,966,800	296,680 μg = 0.1 μg × 2.96 × 10^6
2	Se	12.0 (12000 μg/kg)	0.01	1,200,000	12,000 μg = 0.01 μg × 1.2 × 10^6
3	Pb	73.7 (73700 μg/kg)	< 0.5	> 147,400	73,700 μg = 0.5 μg × 1.474 × 10^5
4	Zn	277.9 (277900 μg/kg)	14	19,850	277,900 μg = 14 μg × 1.985 × 10^4
5	Ni	32.0 (32000 μg/kg)	2.5	12,800	32,000 μg = 2.5 μg × 1.28 × 10^4
6	Cu	146.4 (146400 μg/kg)	13.7	10,686.1	146,400 μg = ±13.7 μg × 1.0686 × 10^4
7	Cd	3.6 (3600 μg/kg)	1.7	2,117.6	3,600 μg = ± 1.7 μg × 2.117 × 10^3
8	Co	27.8 (27800 μg/kg)	17	1,635.2	27,800 μg = ±17 μg × 1.635 × 10^3
9	As	2.0 (2000 μg/kg)	< 2	> 1,000	2,000 μg = 2 μg × 1.0 × 10^3

Table 4 BCF values of the three MTEs (As, Cd, Pb) for fish from the togolese lagoon system (Togo) compared to the BCFs of the same MTs (As, Cd, Pb) for fish from the Kafubu River at the Kamilombe site (DR Congo).

No.	Fish of the togolese lagoon system (Togo)	F_{BC} As	F_{BC} Cd	F_{BC} Pb	Observations
1	*Synodontis schall*	4.15	7.46	10.13	Family Mochokidae
	Tilapia zilii	2.56	7.46	14.87	Family Cyclidae
	Tilapia guineensis	3.35	7.88	11.06	
	Hemochromis faciatus	3.83	20.36	12.57	
2	Fishes of the Kafubu River (Kamilombe site, RD Congo)	> 1,000	2,117.6	147,400	All families combined but majority Cyclidae (12 fish out of 23)

that the Kafubu River has been the victim of this pollution for several decades. And finally, the third explanation for this high bioaccumulation of MTE is that the locality of Kamilombe is already far enough away from the CHEMAF plant (25 km) and especially from the Kipushi Concentrator (47 km) which pollute the Kafubu River via, let us recall, the Lubumbashi River. On this subject, in fact, in our research work on the pollution of aquatic ecosystems and the health safety of fish in the south-east of the DR Congo, we ended up noting that fish further away from polluting metallurgical plants were more contaminated with MTEs than those living very close to these plants. We were happy to discover that this observation was the same as that of Labat et al. [16] according to which “fish poisoning by heavy metals is more significant in populations living very downstream from the source of pollution”.

4.2.4 Health Status of Kafubu Fish

When MTEs are highly bioaccumulated in fish, they must be physically affected. For example, reported effects of Cd on fish include gill and kidney damage, poor bone mineralization, and stunted growth. Effects of Pb on fish include death and body film formation. Thus, it must be noted that when fish have bioaccumulated excess pollutants such as MTE, the risk of consuming unhealthy fish, diseased fish, and in actually poisonous is very great.

After all the above considerations, we believe that the fish of the Kafubu River truly deserve to be called “poisonous”.

4.3 Some Effects of ETMs on Human Health

In chronic arsenic poisoning, liver disorders and neurological disorders are observed [17]. Arsenic also has a carcinogenic effect [17]. In Zimbabwe, Greichus [18] obtained a value of 0.28 mg/kg for Lake McIlwaine, in Zimbabwe, lower than the value obtained in the present study (2.0 mg/kg) at the Kamilombe site.

Prolonged exposure to Cd in humans can induce kidney damage, bone fragility, respiratory system effects, reproductive disorders and an increased risk of cancer, especially in the occurrence of lung cancer [17]. Cd can also cause kidney dysfunction, osteomalacia and reproductive dysfunction [17]. Biney and Beeko [19] obtained a value of 0.19 mg/kg for the Wiwi River in Ghana, much lower than the value obtained in the present study at the Kamilombe site (3.6 mg/kg).

Co is a constituent of vitamin B12 which is essential for the normal formation of red blood cells. However, in excess, it can cause poisoning, including irritation of the respiratory tract, nervous and digestive disorders [17]. Koya [3] obtained a mean value of Co concentrations (1.5 mg/kg) for the Lufira River at the Koni site in DR Congo lower than those obtained in the present study at the Kamilombe (27.8 mg/kg) site.

Chronic exposure to Cu can cause irritation of the affected areas, including the mucous membranes, nasal cavities and eyes. It causes headaches, stomach aches, dizziness, digestive disorders such as vomiting and diarrhea [20]. In addition, excess Cu has been associated with liver degradation [20]. El Nabawi et al. [21] obtained for fish from Lakes Idku and Mariout in Egypt a Cu concentration value of 1.77 mg/kg, much lower than those obtained in this study, i.e. 140.4 mg/kg at the Kamilombe site.

In case of Mn poisoning, respiratory and digestive tract burns accompanied by bloody vomiting are observed. In case of chronic poisoning, neurological lesions are observed in manganese mine workers [17]. The mean Mn concentrations in fish samples from the Kafubu River (296 $\pm$ 218.2 mg/kg at the Kamilombe site) are higher than those obtained by Greichus et al. [22] for the Voelvlei reservoir (0.24 mg/kg) in South Africa.

Acute or chronic Ni poisoning can cause digestive disorders, paralysis of the upper and lower limbs, high blood pressure, and hematological disorders including the destruction of red blood cells [17]. Squadrone et al. [11] obtained, for Lake Tshangalele at the Mwadingusha site (0.11 mg/kg), a lower value than the values obtained in the present study (32.0 mg/kg at the Kamilombe site).

Pb is among the most toxic metals that have no known biochemical benefit to humans or animals; it is not necessary for human life and is harmful in all cases [9]. Pb poisoning, both acute and chronic, manifests itself by digestive disorders, including colic present in cases of severe acute or chronic poisoning, by renal and neurological damage (paralysis of the upper limbs), hematological disorders and thyroid damage [17]. The average Pb concentrations obtained in this study for fish samples from the Kafubu River (73.7 mg/kg at the Kamilombe site) are far higher than the Pb concentration values obtained by Koya [3] for Lake Tshangalele in the Democratic Republic of Congo at the Shinangwa site (0.02 mg/kg).

Ingestion of excessive amounts of Se can be toxic or even fatal. Manifestations of toxicity include hair loss, nausea, vomiting, and muscle pain [23]. The Se concentration value obtained in this study (1.2 mg/kg) is far higher than the values obtained by Koya [3] for the Lufira River in the Democratic Republic of Congo at the Kapolowe-Gare (0.4 mg/kg) and Misisi (0.97 mg/kg) sites.

In case of chronic exposure to Zn, bone marrow and neurological effects can occur. Chronic ingestion of Zn and the resulting Cu deficiency lead to sideroblastic anemia and myelodysplasmic syndrome [24]. The mean Zn concentrations of fish samples from the Kafubu River at Kamilombe (277.9 ±279.8 mg/kg) site is higher and significantly higher than the mean Zn concentration values obtained by Biney [25] for the Kpong Basin (5.6 mg/kg) in Ghana.

5. Conclusion

Through this study, we wanted to understand and assess the health safety of fish from the Kafubu River. The results of the chemical analysis of fish samples, taken both upstream and downstream of mining activities, and the statistical analysis of these results revealed that the fish from the Kafubu River were, when they were taken, contaminated with As, Cd, Co, Cu, Mn, Ni, Pb, Se and Zn. Based on this contamination, the fish from the Kafubu River were deemed unfit for human consumption.

On the other hand, the study of the bioaccumulation of TMEs in fish, by comparing their concentrations to the thresholds established by the WHO, FAO and the EU, as well as by studying their BCF, in particular their comparison with those obtained elsewhere in other studies, also revealed that Mn, Se, Pb, Zn, Ni, Cu, Cd, Co and As were highly bioaccumulated by the fish and so bioconcentrated that the fish of the Kafubu River were eventually described as real poisons for the consuming population.

The pathologies that can be caused in humans by the different TMEs studied in this study have been described in a succinct manner. We wanted to draw the attention of the reader and especially the consumer so that he knows what he can expect by imprudently consuming fish from the Kafubu River. Through this description, we also wanted to draw the attention of the political and administrative authorities to the risk to the health of the population posed by the consumption of fish from aquatic ecosystems polluted by mining waste.

This study provided a response to many inhabitants of the south-east of the Democratic Republic of Congo who often ask us if they can eat fish from a river polluted by mining waste without risk to their health. The main principle that emerges from this study is that fish from an ecosystem polluted by mining waste are not fit for human consumption. In doing so, the results of this study will be brought to the attention of decision-makers in the Haut-Katanga Province, so that rigorous measures are taken to prohibit metallurgical plants from dumping their mining waste into aquatic ecosystems, particularly those that provide fish to the population.

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