Physicochemical characterization of the soils and sediments of nine rivers draining the FIZI gold panning areas in South Kivu: environmental impact study

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Abstract-The monitoring of pollution at the Fizi mining sites in the eastern part of the Democratic Republic of Congo was based on the investigation of mercury contamination in the soil of the rivers draining these sites. The objective of this work is to assess mercury pollution in the soil and sediments of rivers draining the Fizi areas through pollution indices (enrichment factor, geo-accumulation index, contamination factor, potential ecological risk factor and ecological risk index). The levels of metals (sodium, potassium, calcium, magnesium, aluminium, iron and mercury) in soils and sediments were studied in rivers and soils. The study revealed the presence of incredibly significant concentrations, particularly of mercury. Overall, our study highlighted the high levels of mercury contamination at the Fizi mining sites. And that this contamination has various origins to know anthropogenic and geological.

Keywords: **Gold plating, mercury pollution, Pollution index, sediments.**

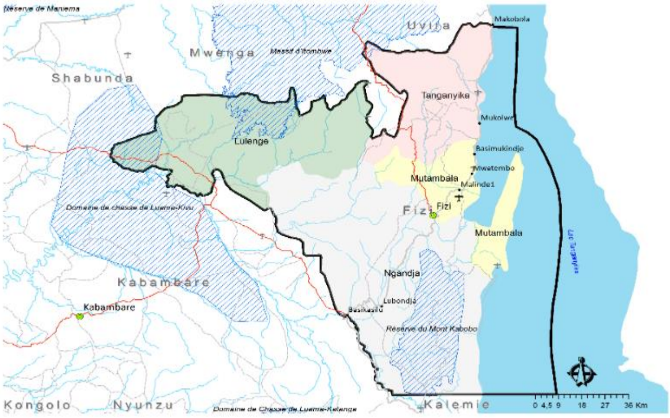
I. INTRODUCTION

Water and soil pollution today remain a major problem for the environment, following intense human activity. Gold quarries are scattered in many territories of the province of South Kivu but most of them are more localized in the territory of Fizi. Currently, gold panning is beating the record in all the gold sites in the Fizi territory, as in those of other gold sites in developing countries in Asia (China, India, Mongolia, Korea, Indonesia, Philippines) [1], Latin America (Bolivia, Amazon) [2, 3] and Africa (Senegal, Ghana, Burkina Faso, Nigeria, Mali, Tanzania, etc.), [4-8]. Through this form of gold mining; marketable gold is extracted from its ores and concentrated through both traditional and manual methods and processes using several reagents [9]. Thus, during gold mining, mercury is generally used to extract gold from ore via the formation of the “gold-mercury” amalgam [10]. This amalgam is then heated to separate merchant gold from mercury by evaporation [11]. This practice of gold panning is responsible for the emission of mercury into the environment in the sense that the mercury vapor produced can be precipitated in the form of acid rain or can be propagated by the action of the wind and contaminate soils, plants, rivers, food chain [12]. Like surface water, the quality of the sediment and soil of the various artisanal gold mining sites in the FIZI territory must be scientifically known in order to avoid ecological and health disasters and contribute to effective and sustainable protection of the environment [9, 13]. Currently, only the work of Nsambu *et al*. [14-17] gives us an overview of the environmental quality of the water, soil and sediments of the gold panning sites in the Fizi territory in South Kivu in the Democratic Republic of Congo. This study focuses on the contamination of sediments and soils by mercury.

II. MATERIAL AND METHODS

II.1. Description of the study environment

The present research took place respectively in Lulimba, in the artisanal gold extraction zones of the Fizi territory as well as in the rivers draining them. The territory of FIZI is one of eight territories in the province of South Kivu in the Democratic Republic of Congo. Geographically, the territory of Fizi is located between 3 ° 30 'and 4 ° 51' 32 " south latitude, 27 ° 45 'and 29 ° 14' 10 " east longitude. This territory administratively shares the borders with the territory of Uvira in the North, the territory of Mwenga and Shabunda in the West, the territory of Kalemie in the South, and Lake Tanganyika in the East [13].



Sampling

Sediment samples were taken 0.5m from the bays by driving the PVC corer into the river. The sediment core thus obtained was packed in a clean 500 ml plastic box, previously labeled. This sampling operation was repeated twice and the constituted samples were mixed in order to form a composite sample which makes it possible to reduce the variation in the results and the uncertainty surrounding the average value obtained during the laboratory analysis of the parameters sought. The soil samples were taken at a depth of 20 cm by pushing the soil probe into the soil in the direction of progression of a screw from left to right while turning it in the opposite direction [15]

Methods

The following parameters were analyzed: The aluminum, mercury and iron concentration is determined by flame photometry at 530 nm [14, 15]. Calcium and magnesium are dosed by complexometry with EDTA and Eriochrome T black as an indicator. Potassium by emission spectroscopy. The electrical conductivity of surface water samples was determined using the conductimetric method described by Rodier [18].

III. RESULTS AND DISCUSSION

The results of our research are shown in Tables 1, 2, 3 and 4 which show the contents of metals (sodium, potassium, calcium, magnesium, iron, aluminium and mercury) for the sediments and soils of gold panning sites but also indices of contamination or mercury pollution (FE, Igeo, FC, FREP and IRE).

Table 1. Metal contents (Na, K, Ca, Mg, Fe, Al and HgT) expressed in mg / Kg of the soils of the gold panning sites.

Ground Settings	Kuwa	Lubichako I	Lubichako II	Lulimba *	Makungu	Misisi	Ngalula	Nyange	Tulonge
Na (mg / Kg)	*0.8*± 0.0	*0.2*± 0.0	*0.5*± 0.0	*0.2*± 0.0	*0.6*± 0.1	*0.2*± 0.0	*0.2*± 0.0	*0.5*± 0.1	*0.6*± 0.1
K (mg / Kg)	*104.9*± 9.8	*62.9*± 5.4	*57.9*± 2.8	*52.3*± 2.1	*84.9*± 8.8	*52.1*± 2.3	*52.6*± 2.2	*70.4*±, 4	*52.6*± 2.3
Ca (mg / Kg)	*1757.3*± 4.1	*1689.5*± 2.2	*1679.1*± 2.2	*537.5*± 2.5	*1726.2*± 4.1	*1046.5*± 1.3	*1,569.1*± 2.0	*1673.7*± 2.3	*1,715.8*± 3.1
Mg (mg / Kg)	*74.5*± 1.6	*83.8*± 2.8	*87.3*± 2.2	*43.3*± 4.7	*69.2*± 2.1	*41.9*± 3.5	*42.1*± 3.7	*57.8*± 1.9	*51.8*± 1.3
Fe (mg / Kg)	*11.0*± 1.9	5.6 ± 0.9	8.8 ± 1.3	2.0 ± 0.1	9.1 ± 1.9	4.9 ± 0.4	8.7 ± 1.2	7.3 ± 0.9	544 ± 0.6
Al (mg / L)	*2.7*± 0.2	*2.0*± 0.0	*2.9*± 0.2	*0.4*± 0.0	*3.2*± 0.2	*1.6*± 0.0	*2.5*± 0.2	*2.2*± 0.0	*2.5*± 0.2
Hg T (mg / Kg)	*11.6*± 0.2	*16.1*± 0.5	*13.8*± 0.3	*0.1*± 0.0	*18.4*± 0.6	*22.4*± 0.7	*8.8*± 0.2	*19.6*± 0.6	*6.9*± 0.1
CE (dS / m)	11.7 ± 0.3	3.1 ± 02	3.0 ± 0.2	2.6 ± 0.1	7.5 ± 0.3	2.6 ± 0.1	1.1 ± 0.0	4.3 ± 0.3	2.9 ± 0.1

The observation of these results relating to the contents of Ca, Mg, Al, Fe, Na and K cations presented in Table 1 shows which: the soils of all the gold panning sites studied are polluted by mercury. Total mercury concentrations greatly exceed the standards of soil qualities which must be ≤ 0.5 mg / Kg. The concentrations of total mercury (HgT) in all our soils at investigation sites except the control site (Lulimba) greatly exceed the WHO standard which fixes the threshold at ≤0.5 mg / kg of soil. The total mercury (Hg T) concentrations of the soils studied are listed in Table 1. The Kuwa site has an average total mercury concentration of 11.6 ± 0.2 mg / Kg of soil, it is 16.1 ± 0.5 mg / Kg for the soil of Lubichako I, an average of 13.8 ± 0.3 mg / Kg for the soil of Lubichako II, it is on average 0.1 ± 0.0 mg/Kg for the control site of Lulimba, the soil of Makungu has an average of 18.4± 0.6

mg/Kg, the most polluted Misisi soil has an average concentration of 22.4± 0.7 mg/Kg; 8.8±0.2 mg/Kg for Ngalula soil, 19.6±0.6 mg/Kg for Nyange soil and 6.9± 0.1 mg/Kg for the soil of Tulonge which remains the least polluted of the others.

With the exception of our control site which is Lulimba, the rest of the sites present with a high content of metals sodium, potassium, calcium, magnesium, aluminum and iron. For example, the soils sampled on the Kuwa site presented the average calcium concentration of 1757.3 ± 4.1 mg / Kg, the soil of Lubichako I with 1689.5 ± 2.2 mg / Kg, Lubichako II 1679.1 ± 2.2 mg / Kg, the soil of Misisi has a content of 1046.5 ± 1.3 mg / Kg; those of the Ngalula, Nyange and Tulonge sites are respectively 1569.1 ± 2.0 mg / Kg, 1673.7 ± 2.3 mg / Kg and 1715.8 ± 3.1 mg / Kg. These pollutions have several causes among others we can cite: the anthropic activities exerted on each site, the geology of the sites studied, the phenomena of atmospheric deposition, the quantities of metallic mercury used in respective quarries, the phenomena of runoff, etc.

The FE ecological factor, Igeo geo-accumulation index, FC contamination factor, potential ecological risk factor FREP and the ecological risk index IRE indices were used for the environmental assessment of the sediments in the study area. The results of these indices (FE, Igeo, FREP and IRE) are presented in Table 2.

Table 2: Results relating to indices of mercury intoxication (FE, Igeo, FC, FREP, IRE) of the soils of all the rivers in the gold mining zones of Fizi according to the campaigns.

Soils Settings	KUWA	LUBICHAKO I	LUBICHAKO II	LULIMBA *	MAKUNGU	MISISI	NGALULA	NYANGE	TULONGE
FE	*22.0*± 0.7	*26.8*± 0.5	*25.2*± 0.4	*0.4*± 0.0	*28.1*± 0.5	*40.1*± 0.8	*20.1*± 0.8	*31.1*± 0.4	*19.6*± 0.7
Igeo	*4.3*± 0.1	*4.6*± 0.3	*4.5*± 0.5	*0.7*± 0.1	*4.7*± 0.3	*4.9*± 0.7	*4.2*± 0.3	*4.8*± 0.4	*4.1*± 0.2
FC	*6.9*± 0.1	*7.5*± 0.2	*7.3*± 0.1	*0.1*± 0.0	*7.8*± 0.5	*9.2*± 0.8	*6.7*± 0.0	*8.3*± 0.7	*6.4*± 0.1
FREP	*170.3*± 3.2	*185.8*± 4.2	*173.3*± 3.2	*2.8*± 0.1	*191.2*± 0.2	*207.1*± 3.4	*169.3*± 0.2	*197.3*± 0.3	*165.9*± 3.1
IRE	*494.1*± 2.7	*507.8*± 2.9	*502.4*± 3.1	*33.2*± 1.2	*518.3*± 3.0	*585.4*± 3.6	*477.6*± 3.6	*552.5*± 3.6	*470.9*± 2.4

The mercury enrichment factors in the soils of the sites studied (Lulimba, Misisi, Lubichako I, Lubichako II, Tulonge, Ngalula, Kuwa, Makungu and Nyangé) are listed in Table 4. We used a non-mining site as the site for reference. The soils of the Lulimba reference site (non-mining site) showed a low value of EF in mercury, an average of 0.4 ± 0.0 compared to the soils of other sites studied. Furthermore, the soils at the Misisi gold panning site had the highest average value of EF in mercury compared to the average values of EF in mercury from the soils of other gold panning sites 40.1 ± 0.8 followed successively the soils of the gold washing sites of Nyangé 31.1 ± 0.4, Makungu 28.1 ± 0.5, Lubichako I 26.8 ± 0.5 and Lubichako II 25.2 ± 0, 4 whose mercury enrichment factor values are statistically identical; finally, the soils at the Kuwa, Ngalula and Tulonge sites presented respective values of 22.0 ± 0.7; 20.1 ± 0.8 and 19.6 ± 0.7 with statistically similar mercury enrichment factor values.

In terms of intensity of mercury pollution from said sites, it is noted that anthropogenic enrichment in mercury was nonexistent or weak in the soils of the Lulimba reference site (non-mining site) especially as their average factor value enrichment was less than 2. In addition, anthropogenic mercury enrichment was respectively extreme in the soils of the Misisi gold panning site (because FE≥40); very strong in the soils of the gold washing sites of Nyangé, Makungu, Lubichako I, Lubichako II, Kuwa and Ngalula (bus 20<FE<40); significant in the soils of the Tulonge gold panning site. The same observation is made for: the geo-accumulation index of mercury, the mercury contamination factor, the potential ecological risk factor and the ecological risk index. From this observation, it should be noted that the Misisi site remains the most polluted compared to the other gold panning sites and to our control site which is the Lulimba site as shown in Table 4. The variations in contamination indices (CI) or pollution indices (PI) of the soils studied would be due to anthropic activities carried out at each site, from the geology of the sites studied, to gold panning effluents, to atmospheric deposition phenomena , the amounts of metallic mercury used in respective quarries, runoff phenomena, etc.

Table 3. Metal contents (Na, K, Ca, Mg, Fe, Al and HgT) expressed in mg / Kg of the sediments of the gold panning sites.

Sediments Settings	Eto '	Kacumvi	Kimbi	Kimuti	Kuwa	Lubichako	Makungu	Mandje	Misisi
Na (mg /	*13.8*± 0.2	*10.5*± 0.1	*26.4*± 0.4	*7.374*± 0.1	*8.6*± 0.2	*11.7*± 0.1	*12.6*± 0.2	*9.5*± 0.1	*13.8*± 0.1

Kg)									
K (mg / Kg)	200.2± 3.2	185.5± 4.0	322.2± 3.4	185.7± 5.0	186.3± 3.4	187.3± 5.0	190.7± 3.0	185.7± 3.0	229.3± 0.33
Ca (mg / Kg)	1630.1± 8.2	1726.9± 7.7	2,595.2± 16.8	1710.1± 17.3	1,721.8± 9.8	1,735.4± 8.1	1,732.4± 10.9	1,713.7± 13.6	1,830.6± 6.1
Mg (mg / Kg)	113,2± 5.7	94.5± 2.3	183.3± 4.7	92.4± 2.4	96.9± 5.3	98.5± 7.3	102.1± 0.3	95.9± 2.3	119.5± 4.7
Fe (mg / Kg)	12.3± 0.8	7.2± 0.2	23.0± 1.0	6.8± 0.1	7.8± 0.17	9.5± 0.3	10.2± 0.6	7.9± 0.4	12.7± 0.8
Al (mg / Kg)	3.1± 0.1	2.8± 0.1	5.9± 0.2	2.51± 0.4	2.8± 0.1	3.0± 0.0	3.1± 0.1	2.6± 0.2	2.9± 0.6
Hg T (mg / Kg)	33,7± 0.1	25.3± 0.3	89.8± 0.9	13.6± 0.5	19.9± 0.5	30.1± 0.1	36.9± 0.4	17.1± 0.5	41.9± 0.3
THIS	12.7± 0.4	7.8± 0.2	23.4± 0.2	7.6± 0.3	8.6± 0.2	8.7± 0.5	11.5± 0.5	8.7± 0.4	12.0± 0.4

The sediments of all the rivers in the gold panning sites studied are polluted by mercury. Total mercury concentrations greatly exceed the sediment quality standards which must be ≤ 0.4 mg / Kg. The sediments of the Kimbi river showed the highest HgT content, 89.811 ± 0.851 mg / Kg followed by the sediments of the Misisi rivers 41.9 ± 0.3 mg / Kg, Makungu 36.9 ± 0.4 mg / Kg respectively Kg, Etó 33.7 ± 0.1 mg / Kg, Lubichako 30.1 ± 0.1 mg / Kg, Kacumvi 25.3 ± 0.3 mg / Kg, Kuwa 19.9 ± 0.5 mg / Kg, Mandje 17.1 ± 0.5 mg / Kg) and Kimuti 13.6 mg / Kg. The Kimbi river being the confluence of its rivers, this explains the levels observed.

For example, the sediments sampled in the Kimbi river showed the highest average concentration of sodium ions compared to those of sediments sampled in other rivers (26.4 ± 0.4 mg / Kg) followed alternately sediments from the rivers Etó (13.8 ± 0.2 mg / Kg) and Misisi (13.8 ± 0.1 mg / Kg) whose mean values of sodium ion contents are statistically identical; Makungu (12.5 ± 0.3 mg / Kg); Lubichako (11.7 ± 0.1 mg / Kg); Kacumvi (10.5 ± 0.1 mg / Kg); Mandje (9.5 ± 0.1 mg / Kg); Kuwa (8.6 ± 0.2 mg / Kg); Kimuti (7.4 ± 0.1 mg / Kg). The same observation is made for metals such as potassium with an average content of 322.2 ± 3.4 mg / Kg, calcium which has the content of 2595.2 ± 16.8 mg / Kg, magnesium with a concentration of 183.3 ± 4.7 mg / Kg, the iron has a concentration of 23.0 ± 0, 1 mg / Kg and aluminum with an average of 5.9 ± 0.2 mg / Kg. The least polluted river of nine remains the Kimuti as shown in Table 1.

Table 4: Results relating to indices of mercury intoxication (FE, Igeo, FC, FREP, IRE) of the sediments of all the rivers in the gold mining zones of Fizi according to the campaigns.

Rivers Settings	Eto '	Kacumvi	Kimbi	Kimuti	Kuwa	Lubichako	Makungu	Mandje	Misisi
FE	24.3 ± 0.5	21.4 ± 0.3	37.9± 0.1	19.5± 0.3	21.5± 0.1	22.5 ± 0.3	26.3± 0.6	20.6± 0.1	26.9± 0.1
Igeo	4.6 ± 0.1	4.5 ± 0.7	6.7± 0.7	4.2± 0.4	4.5± 0.4	4.5 ± 0.6	4.8± 0.2	4.4 ± 0.2	4.8± 0.2
FC	9.4 ± 0.5	8.5± 0.3	14.2± 0.4	7.6± 0.4	8.1± 0.1	8.7± 0.4	9.8 ± 0.2	7.92± 0.1	9.9± 0.4
FREP	195.4± 0.3	182.3± 0.2	252.5± 2.0	166,878± 2.5	178.4± 3.2	190.7± 1.7	202.5± 4.3	173.8± 3.2	211.6± 2.8
IRE	544.6 ± 2.0	533.6 ± 4.5	590.4 ± 4.2	502.7 ± 5.6	521.410 ± 5.6	540.3 ± 5.5	553.6 ± 0.4	513.0±3. 4	556.0 ± 4.3

Results relating to mercury intoxication indices (FE, Igeo, FC, FREP, IRE) of the sediments of all the rivers in the gold mining zones of Fizi according to the campaigns shows that the Kimbi river which is our confluence remains the most polluted with mean values of EF Enrichment Factor (37.9 ± 0.1), of the Igeo Geo-accumulation Index (6.7 ± 0.7), the mercury contamination factor FC (14.2 ± 0.4), the potential ecological risk factor FREP (252.5 ± 2.0) and the ecological risk index IRE (590.4 ± 4, 2) in sediments. The least polluted river of all the rivers studied remains the Kimuti with average values of FE (19.5 ± 0.3), Igeo (4.2 ± 0.4), HR (7.6 ± 0.4) , FREP (166.9 ± 2.5) and IRE (521.4 ± 5.6) in sediments as shown in Table 2. These observed variations would come from anthropogenic activities, gold panning activities, quantities of metallic mercury used in respective mining quarries, phenomena of atmospheric deposition on the one hand and different gold panning effluents on the other hand.

IV. CONCLUSION

We note that the soils and sediments analysed are of the saline type regarding the high content of sodium, magnesium, potassium and calcium observed. In addition, we were able to observe that all our sediments were polluted because they contained values higher than the values required in the standard. The sediments of all the rivers in the gold panning sites studied are polluted by mercury. Total mercury concentrations greatly exceed the sediment quality standards which must be ≤ 0.4 mg / Kg.

The soils of all the gold panning sites studied are also polluted by mercury like sediments. Total mercury concentrations greatly exceed the standards of soil qualities which must be ≤ 0.5 mg / Kg.

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