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

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Abstract-Nine rivers (Etó, Kacumvi, Kimbi, Lubichako, Makungu, Kuwa, Mandje, Misisi and Kimuti) has been followed during a 16-month cycle (August and December 2016 to August and December 2017) to assess the level of mercury pollution and phy sicochemical quality of water during the dry and rainy season. Twenty-three parameters in general were measured (T °, pH, electrical conductivity, total hardness, sulphates, ortho-phosphates, chlorides, dissolved oxygen, suspended solids, organic matter, and nitrogen compounds. The last Kimbi River is the most polluted of all with values strongly deviating from the WHO average followed alternately by the Kuwa, Makungu, Lubichako, Lacumvi, Kimuti, Mandjo, Misisi and Eto' for all parameters except mercury. The mercury concentration is greater for the Kimbi River with an average of 41.3 ± 0.4 ng / L, followed by the Misisi River 20. 30 0.29 Misisi 20.30 ± 0.29 ng / L, Misisi 20.30 ± 0.29 ng / L, Makungu 18.10 ± 0.17 ng / L, Eto '16.7 ± 0.1 ng / L , Lubichako 15.7 ± 0.4 ng / L, Kacumvi 12.9 ± 0.3 ng / L, Kuwa 10.7 ± 0.4 ng / L, Mandje 9.4 ± 0.2 and Kimuti 7.8 ± 0.3 ng / L. All these eight rivers are tributaries of the Kimbi River, which shows its high pollution. There are no significant differences between the two seasons. This pollution is a consequence of the activities of the ore bodies as well as the solid and liquid wild discharges that have a direct and significant impact on water quality. Human anthropogenic actions (wastewater discharges, agricultural and artisanal activities) without prior treatment are the main cause of the pollution generated. This pollution is a consequence of the activities of the ore bodies as well as the solid and liquid wild discharges that have a direct and significant impact on water quality. Human anthropogenic actions (wastewater discharges, agricultural and artisanal activities) without prior treatment are the main cause of the pollution generated.

Key words: Fizi territory, gold panning, mercury pollution, rivers.

INTRODUCTION

Water pollution today remains a major problem for the environment; water quality continues to deteriorate due to human activity (uncontrolled industrial discharges, handicrafts and the intensive use of chemical fertilizers in agriculture) [1]. This has the consequence of reducing the quality of the water making it unsuitable for the uses for which it is called [2, 3]. Nowadays there are many works on the study of the different rivers regarding their qualities and their levels of pollution. Reggan *et al.*, [4] have shown that industrial activities whose discharges are discharged into rivers directly affected water quality. Idowu *et al.*, [5] assessed the level of mercury contamination in the Manyera river waters of the gold panning sites in Nigeria. At present, there is no information on the gold mining sites of DR Congo and of the province of South Kivu in general, as well as those of the Fizi territory, on the risks of human health and of the terrestrial and marine environment linked to mercury pollution, neither of the data on the bodily and environmental loads of mercury, nor of the clarifications on the mercury content in fish and benthic macro-invertebrates. The only information we have to date comes from the work of Nsambu *et al.* [6-9] on the various rivers in the territory of Fizi in South Kivu. This being the case, the present study seeks to fill these aforementioned gaps.

MATERIAL AND METHODS

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 [6, 7, 9, 10].

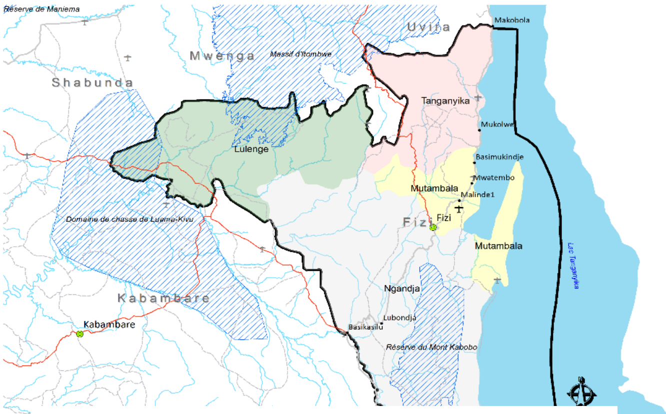

Figure 1. Map showing the study area

2. Sampling

During our campaigns, the water is sampled in clean plastic bottles with a capacity of 500 mL at 2 m from the banks. The bottles are filled to the brim and then closed to avoid any gas exchange and contamination with atmospheric gas. Then the water samples are brought directly to the laboratories for analysis. Three rivers have been studied; they are chosen in relation to gold panning activities.

3. Methods

The following parameters were analyzed: temperature and pH were measured on site according to [2]. The aluminum and iron concentration is determined by flame photometry at 530 nm [2]. Calcium and magnesium are dosed by complexometry with EDTA and Eriochrome T black as an indicator. Potassium by emission spectroscopy [9]. The phosphate ions are assayed by spectrometry at 720nm, the ammonium ions are assayed by colorimetry at 630nm while the nitrate ions are assayed by UV spectrometry at 415nm and the sulfides at 664nm. Total solids are determined by calcination at 180 ° C. Turbidity is determined by nephelometry. Sulphate ions are measured by gravimetry (George et al. 2013). Organic matter and silicate ions by the method described by Bitar [9]. Dissolved organic carbon and chlorides by the method described by [7]. BOD and dissolved oxygen are determined by the ProODO device [11]. The MES are determined by steaming at 105 ° C.

RESULTS AND DISCUSSION

The results of our research are shown in Tables 1 with the following parameters: temperature, pH, suspended solids, dissolved solids rate, turbidity, electrical conductivity, dissolved oxygen, dissolved organic carbon and soluble salts. The sulphate, nitrates, ammonium, phosphate, sulphides, chlorides and carbonates ions are presented in table 2. Table 3 presents the results of the metal cations: calcium, sodium, potassium, magnesium, aluminum, iron and mercury**. Table 4. Correlations between the variables and the main axes of the overall PCA for the "water" compartment.**

Table 1. Physico-chemical parameters of the nine rivers studied

Rivers Settings	Eto '	Kacumvi	Kimbi	Kimuti	Kuwa	Lubichako	Makungu	Mandje	Misisi
T ° C	28.8 ± 0.2	28.1 ± 0.4	28.7 ± 0.2	30.0 ± 0.2	25.6 ± 0.4	29.9 ± 0.2	23.7 ± 0.2	27.9 ± 0.2	27.6 ± 0.4
pH	7.5 ± 0.4	6.9 ± 0.5	7.3 ± 0.7	7.9 ± 0.2	7.1 ± 0.3	8.0 ± 0.4	7.1 ± 0.1	7.1 ± 0.5	6.5 ± 0.4
SM (mg/L)	74.2 ± 0.3	55.1 ± 0.5	330.3 ± 3.1	56.8 ± 0.7	67.8 ± 0.3	125.7 ± 2.3	95.1 ± 1.3	38.6 ± 0.8	73.2 ± 1.3
TDS (mg/L)	519.4 ± 6.0	562.3 ± 4.2	939.8 ± 6.1	658.2 ± 4.2	816.9 ± 6.2	700.1 ± 5.9	730.1 ± 5.2	540.0 ± 4.3	538.6 ± 5.2
Turbidity (NTU)	7.3 ± 0.2	8.8 ± 0.5	39.4 ± 0.5	13.0 ± 0.3	7.2 ± 0.1	20.2 ± 0.3	13.8 ± 0.2	10.5 ± 0.2	7.7 ± 0.2
EC (dS/m)	5.4 ± 0.5	8.1 ± 0.5	108.5 ± 2.2	28.0 ± 0.2	69.6 ± 1.2	48.5 ± 0.3	14.0 ± 0.3	17.7 ± 0.1	4.9 ± 0.2
O_{2d} (mg/L)	4.9 ± 0.1	4.82 ± 0.3	0.5 ±0.0	2.4 ± 0.4	5.5 ±0.2	2.4 ± 0.2	2.6 ± 0,2	3.8 ± 0.9	4,4± 0.1
DOC (mg/L)	13.2 ± 0.3	12.3 ± 0.3	211.2 ± 4.8	12.6 ± 0.2	13.1 ± 0.3	24.7 ± 0.4	19.5 ± 0.4	13.4 ± 0.2	12.3 ± 0.2
SS (mg / L)	548.1 ± 4.3	636.2 ± 3.2	1270.3± 8.2	929.1 ± 5.1	832.3 ± 3.1	754.8 ± 4.3	609.0 ± 4.1	535.3 ± 2.2	562.6 ± 3.2

Temperature (T °), suspended matter (SM), electrical conductivity (EC), turbidity (NTU), total dissolved solids TDS, hydrogen potential (pH), dissolved oxygen (dissolved O2, dissolved organic carbon (DOC), soluble salts.

Temperature

The waters of the rivers of the gold-washing zones of the Fizi territory are of medium to poor qualities since their temperatures are generally included either in the range of waters of medium qualities (20 to 25 ° C), or in the range of waters of poor quality (25 to 30 ° C). It should be noted that these variations in river water temperatures thus observed may be due to the increase in the contents of suspended matter. These variations in temperature can contribute in one way or another to reducing the quality of habitat for cold water organisms. The high temperatures thus observed could be explained by the influence of ambient heat on the water sampled and by the geothermal gradient of the area Degbey *et al.* [1] as well as by increasing the contents of suspended matter [3]. They are close to those found by Idowu et al. [5] in Nigeria as well as Mickael et al. [12] in Cotonou in Benin.

Hydrogen potential (pH)

The waters of all rivers in the artisanal gold mining regions of Fizi presented an average pH value of around 7.6 ± 0.4 which is normal or meets acceptable standards for rivers water quality stipulating that the normal pH values of river waters must vary between 6.5 and 8.5.

Suspended matter (SM)

The suspended solids contents of the waters vary highly significantly depending on the river. It is approximately 55.1 ± 0.5 mg / L for the Kacumvi river, 74.2 ± 0.3 mg / L for Eto ', 330.3 ± 3.1 mg / L for the Kimbi, 56, 8 ± 0.7 mg / L for Kimuti, 67.8 ± 0.3 mg / L for Kuwa, 125.7 ± 2.3 mg / L for Lubichako, 95.1 ± 1.3 mg / L for Makungu, 38.6 ± 0.8 mg / L for Mandje and 73.2 ± 1.3 mg / L for Misisi river. The Kimbi River remains the most polluted despite the season. It should be noted that the classification of pollution in relation to suspended solids is as follows: significant pollution (30 mg / L ≤SM ≤ 70 mg / L) and excessive pollution (SM > 70 mg / L). These suspended matters affect the transparency of the water while reducing the penetration of light, affect photosynthesis and interfere with aquatic respiration. Such an increase in the SM content can cause the water to heat up, which will reduce the quality of the habitat for aquatic organisms [3].

Total Dissolved Solids (TDS)

The total dissolved solids content of all these waters exceeds acceptable standards for water qualities (TDS ≤ 500 mg / L). The waters of the Kimbi River presented a higher value compared to that of the waters of other rivers (939.8 ± 6.1 mg / L) and much higher than the WHO standard (TDS ≤500 mg / L). These variations in the total dissolved solids concentrations would come from natural sources, gold panning effluents, runoff from land in mining quarries, etc. Furthermore, the high values observed in the Kimbi River would be explained by the quantity of total dissolved solids brought by the waters of other rivers which flow into Kimbi, especially since they are its tributaries [13].

Turbidity

From the point of view of turbidity, all the waters of rivers are cloudy because their turbidities greatly exceed the acceptable threshold of around 5 NTU at most. The waters of the Kimbi River had a higher average turbidity value than those of the other rivers (39.4 ± 0.5 NTU). These variations in turbidity are due to the quantities of suspended matter contained in river waters, to colloidal or fine dispersions, to the phenomena of rainwater runoff, to the phenomena of resuspension of sediments previously deposited in rivers, etc. However, the highest turbidity observed in the waters of the Kimbi River can be explained by the quantity of suspended matter brought in by the other rivers that flow into Kimbi, especially since they are its tributaries. These results greatly exceed the standards of river water qualities such as those obtained by [7] stipulating that the average turbidity of Chari was around 17.10 NTU.

Electrical conductivity (EC)

It should be noted that the mineralization of the waters of all the rivers in the Fizi gold panning area is extremely poor because all the electrical conductivities measured are > 3 dS / m. The waters of the Kimbi River presented an average value of electrical conductivity higher than that of the waters of other rivers (108.5 ± 0.3 dS / m). The variations are not significant from one season to another as shown in Table 1. These variations in the conductivities thus observed between these rivers, would come from the effluents brought during gold panning, waters rich in ions brought by leaching rain, etc. Compared to the results of previous work, the results of this study agree with those obtained by [14, 15].

Dissolved oxygen

It appears from these results that the waters of our rivers except the Kimbi river are polluted while the waters of the Kimbi river 0.5 ± 0.0 mg / L are of poor quality because the average oxygen value dissolved for water is approximately 6 mg / L. We have small fluctuations with respect to the seasons for the Eto 'river as shown in Table 1 above.

Dissolved organic carbon (DOC)

The waters of our rivers except the Kimbi River have average dissolved organic carbon values between 12.3 ± 0.3 mg / L and 24.7 ± 0.4 mg / L which qualifies it for rivers polluted while the waters of the Kimbi River with average values of 211.2 ± 0.2 mg / L are considered to be of poor quality because the average acceptable value is 7 mg/L for water. This high concentration (211.2 ± 0.2) of dissolved organic carbon in the waters of the Kimbi river is explained by the contribution of organic matter to its aquatic ecosystem via the waters of these two rivers which flow into Kimbi given that they are its tributaries. We observe significant variations compared to the campaigns for the Kimbi river.

Soluble salts

The waters of the Kimbi River had the highest average concentration of soluble salts compared to those of the waters of other rivers (1270.3 ± 8.2 mg / L). This high concentration is due to the load of the other eight rivers which are the tributaries of the Kimbi river.

Table 2. Concentration in (mg / L) ofsulphate ions, nitrates, ammonium, phosphate, sulphides, chlorides and carbonates of our rivers during the investigation campaign.

Rivers / Settings	Eto '	Kacumvi	Kimbi	Kimuti	Kuwa	Lubichako	Makungu	Mandje	Misisi
S^{2-} (mg / L)	*9.0* ± *0.3*	*3.5* ± *0.1*	67.2 ± 1.1	43.4 ± 0.2	33.2 ± 0.1	25.9 ± 0.1	15.0 ± 0.5	71.8 ± 0.7	5.9 ± 0.4
SO_4^{2-} (mg / L)	*273.7* ± *3.2*	*265.7* ± 4.2	424.9 ± 5.2	287.4 ± 1.3	369.9 ± 4.1	316.6 ± 2.2	325.1 ± 3.2	327.2 ± 3.1	280.3 ± 2.8
NH_4^+ (mg / L)	*5.7* ± *0.4*	*13.5* ± *0.2*	77.5 ± 1.4	62.2 ± 1.8	34.5 ± 0.4	9.6 ± 0.6	13.54 ± 0.6	33.6 ± 2.3	5.7 ± 0.3
NO_3^- (mg / L)	*33.6* ± *0.3*	*28.4* ± *3*	104.1 ± 3.3	77.1 ± 1.3	69.9 ± 0.4	65.5 ± 0.5	38.9 ± 0.4	55.4 ± 0.6	34.9 ± 0.3
CO_3^{2-} (mg / L)	*81.0* ± *0.2*	*182.9* ± *3.7*	268.9 ± 5.2	183.6 ± 3.2	27.1 ± 0.6	144.4 ± 1.5	137.5 ± 2.2	140.1 ± 3.4	61.9 ± 0.5
Cl^- (mg / L)	*271.1* ± *0.2*	*281.0* ± *0.2*	398.0 ± 3.1	392.9 ± 2.1	276.9 ± 3.2	286.7 ± 3.2	303.9 ± 3.1	264.9 ± 3.1	270.4 ± 2.3
PO_4^{3-} (mg / L)	*6.7* ± *0.1*	*4.6* ± *0.1*	61.0 ± 1.3	2.9 ± 0.1	16.9 ± 0.2	25.8 ± 0.4	8.4 ± 0.2	3.6 ± 0.6	4.6 ± 0.6

The waters of our nine rivers in the Fizi gold panning zones have average values above normal. The concentrations of sulphide, ammonium and phosphate ions greatly exceed the average of ≤ 1 mg / L as recommended by the WHO. As an example, we have for the Eto 'river average values of 9.2 ± 0.3 mg / L, 5.7 ± 0.4 mg / L and 6.7 ± 0.1 mg / L respectively for S^{2-}, NH_4^+ and PO_4^{3-} ions. These values are 3.5 ± 0.1 mg / L, 13.5 ± 0.6 mg / L and 4.6 ± 0.1 mg / L respectively for the ions S^{2-}, NH_4^+ and PO_4^{3-} in waters of the Kacumvi river against 67.2 ± 1.1 mg / L, 77.5 ± 1.2 and 61.0 ± 1.3 mg / L respectively for the ions S^{2-}, NH_4^+ and PO_4^{3-} in the waters of the river Kimbi. The concentrations of sulphate and chloride ions in our rivers exceed the average of the WHO standard, namely an average ≤ 250 mg / L. By comparing it with each other, we note that the Kimbi river remains the most polluted with an average of 424.9 ± 5.2 mg / L for sulphate ions and 398.1 ± 3.1 mg / L for chloride ions. The same observation is made for the concentrations of nitrates and carbonates ions. The high pollution observed in the Kimbi River originates from the load of each of our eight rivers which serve as its tributaries. From an environmental point of view, our rivers are polluted, and these waters unfit for human consumption. Similar results have been found by Maoudombaye *et al*. [16], Bermudez-Lugo [17]. The high pollution observed in the Kimbi River originates from the load of each of our eight rivers which serve as its tributaries. From an environmental point of view, our rivers are polluted, and these waters unfit for human consumption. Similar results have been found by Maoudombaye et al. [16] and Bermudez-Lugo [17]. The high pollution observed in the Kimbi River originates from the load of each of our eight rivers which serve as its tributaries. From an environmental point of view, our rivers are polluted, and these waters unfit for human consumption.

Table 3. Concentration of metals (Ca, Na, K, Mg, Al, Fe) expressed in mg / L and mercury expressed in ng / L of water from our rivers.

Rivers / Settings	Eto '	Kacumvi	Kimbi	Kimuti	Kuwa	Lubichako	Makungu	Mandje	Misisi
Ca^{2+} (mg / L)	49.5 ± 0.3	*169.2 ± 0.3*	216.5 ± 1.2	172.9 ± 1.4	77.8 ± 0.5	138.1 ± 1.2	143.5 ± 1.3	116.4 ± 1.2	74.6 ± 2.3
Na^{+} (mg / L)	64.6 ± 0.9	16.4 ± 0.6	305.9 ± 2.4	39.3 ± 0.1	57.3 ± 0.3	34.8 ± 0.4	33.9 ± 0.7	13.4 ± 0.8	115.8 ± 1.5
K^{+} (mg / L)	20.2 ± 0.4	15.2 ± 0.30	246.9 ± 2.7	50.5 ± 0.2	47.8 ± 0.7	70.2 ± 0.9	40.3 ± 0.8	39.8 ± 0.8	25.7 ± 0.9
Mg^{2+} (mg / L	64.8 ± 0.6	132.9 ± 2.6	176.5 ± 1.5	97.8 ± 0.5	37.2 ± 0.2	71.8 ± 0.8	85.2 ± 1.5	57.8 ± 0.6	38.1 ± 0.3
Al^{3+} (mg / L)	7.6 ± 0.2	6.8 ± 0.3	55.8 ± 0.4	10.1 ± 0.5	57.5 ± 0.5	25.3 ± 0.4	14.9 ± 0.1	12.3 ± 0.1	6.9 ± 0.1
Fe^{3+} (mg / L)	7.9 ± 0.1	14.2 ± 0.2	76.4 ± 0.6	64.6 ± 0.5	43.8 ± 0.5	11.6 ± 0.3	16.3 ± 0.4	26.9 ± 0.4	8.3 ± 0.2
HgT (ng / L)	16.7 ± 0.1	12.9 ± 0.3	41.3 ± 0.4	7.8 ± 0.3	10.7 ± 0.3	15.1 ± 0.4	18.1 ± 0.2	9.4 ± 0.2	20.3 ± 0.3

Based on the results relating to the contents of Ca^{2+}, Mg^{2+} cations; Al^{3+}; Fe^{2+}; Na^{+} and K^{+} contained in Table 3, it should be noted that: The average content of **calcium** for the waters of the Eto 'rivers (49.5± 0.3 mg / L) and Misisi (74.6 ± 2.3 mg / L) is in the WHO standard which requires a concentration <100 mg / L while for the remaining seven rivers, these values s 'deviate from the norm. For example, the Kacumvi river has an average content of 169.2 ± 0.3 mg / L while the Kimbi river has average values of around 216.5 ± 1.2 mg / L. The magnesium content of our rivers exceeds normal (<50 mg / L), namely 64.8 ± 0.6 mg / L for the Eto 'river against 132.9 ± 2.6 mg / L and 176.5 ± 1.5 mg / L for the Kacumvi and Kimbi rivers respectively; only the Misisi and Kuwa rivers are below the standard as shown in Table 3. The aluminum content of our rivers also exceeds the standard (<5 mg / L) with average values of 7.6 ± 0 , 2 mg / L for the Eto 'river, 6.8 ± 0, 3 mg / L for the Kacumvi river and 55.8 ± 0.4 mg / L for the Kimbi river. The iron concentration of our rivers is above the standard set by the WHO (<5 mg / L), the Kimbi river remains the most polluted with an average concentration of 76.4 ± 0.6 mg / L. As with other metals, sodium and potassium give us the same trend with values that deviate considerably from the means (≤10 mg / L for Na and ≤ 12 mg / L for K). the most polluted remains the Kimbi River with average Na and K values of 305.9 ± 2.4 mg / L and 246.9 ± 2.7 mg / L, respectively. There were no incredibly significant variations from the survey campaigns. the Kimbi river remains the most polluted with an average concentration of 76.4 ± 0.6 mg / L. As with other metals, sodium and potassium give us the same trend with values that deviate considerably from the means (≤10 mg / L for Na and ≤ 12 mg / L for K). the most polluted remains the Kimbi River with average Na and K values of 305.9 ± 2.4 mg / L and 246.9 ± 2.7 mg / L, respectively. There were no incredibly significant variations from the survey campaigns. the Kimbi river remains the most polluted with an average concentration of 76.4 ± 0.6 mg / L. As with other metals, sodium and potassium give us the same trend with values that deviate considerably from the means (≤10 mg / L for Na and ≤ 12 mg / L for K). the most polluted remains the Kimbi River with average Na and K values of 305.9 ± 2.4 mg / L and 246.9 ± 2.7 mg / L, respectively. There were no incredibly significant variations from the survey campaigns [6].

The concentrations of total mercury (HgT) in all our nine rivers greatly exceed the WHO standard which fixes the threshold at 6 ng / L of water for rivers. The concentrations of total mercury (HgT) in the waters of our rivers are shown in Table 3. The Eto 'river has an average concentration of total mercury is16.7 ± 0.1 ng / L of water, it is 12.9 ± 0.3 ng / L of water for the Kacumvi river, an average of 41.3 ± 0.4 ng / L of water for the Kimbi river, it is on average 7.8 ± 0.3 ng / L of water for the Kimuti river, the Kuwa river has an average of 10.7 ± 0.4 ng / L of water, the Lubichako river has an average concentration of 15.1 ± 0.4 ng / L of water, it is 18.1 ± 0.2 ng / L of water for the Makungu river, of 9.4 ± 0.2 ng / L for the Mandje river and 20.3 ± 0.3 ng / L for the Misisi river. In light of this table, we see that the Kimbi River is the most polluted with an average concentration of 41.33 ± 0.36 ng / L; this heavy pollution is mainly due to the artisanal mining of gold washers on the one hand and tributaries on the other.By way of comparison with the aquatic ecosystems of other rivers affected by gold panning activities, it turns out that the high values of the total mercury concentrations noted in this study agree with those reported in the studies carried out successively by Jacqueline et al. [18] who found the average HgT of 22 ng / L of water in the gold panning site in Senegal, Noah and Anthony (2016) found 145 ng / L of HgT in the Ankobra and Tano rivers draining gold panning areas in southwest Ghana, Idowu et al. [5] found 147 ng / L of HgT in the Manyera River in Nigeria, Ouédraogo et al., [19] found a value of 21, 38 ng / L of HgT in Burkina Faso ; Lusilao-Makiese et al. [20] found the value of 253 ng / L of HgT in South Africa.

Table 4. Correlations between the variables and the main axes of the global PCA for the "water" compartment

Variables	Eigen vectors		Coordinated variables		Correlation between variables and factors		Square Cosines	
	F1	F2	F1	F2	F1	F2	F1	F2
pH	0,000	0.197	0.001	0.253	0.001	0.253	0,000	0.064
T	0.078	0.390	0.351	0.501	0.351	**0.501**	0.123	**0.251**
MY	0.215	-0.045	0.967	-0.058	**0.967**	-0.058	**0.935**	0.003
OD	-0.201	-0.207	-0.903	-0.266	**-0.903**	-0.266	**0.816**	0.071
COD	0.216	-0.030	0.973	-0.039	**0.973**	-0.039	**0.946**	0.002
NO_3^-	0.209	-0.068	0.938	-0.087	**0.938**	-0.087	**0.880**	0.008
NH_4^+	0.205	0.036	0.921	0.047	**0.921**	0.047	**0.849**	0.002
PO_4^{3-}	0.215	-0.117	0.966	-0.150	**0.966**	-0.150	**0.933**	0.023
S^{2-}	0.078	0.006	0.352	0.007	0.352	0.007	0.124	0,000
SO_4^{2-}	0.185	-0.236	0.834	-0.303	**0.834**	-0.303	**0.695**	0.092
CO_3^{2-}	0.194	0.329	0.873	0.423	**0.873**	0.423	**0.762**	0.179
Ca^{2+}	0.193	0.273	0.868	0.350	**0.868**	0.350	**0.753**	0.123
Mg^{2+}	0.198	0.218	0.893	0.280	**0.893**	0.280	**0.797**	0.078
Al^{3+}	0.178	-0.385	0.803	-0.495	**0.803**	-0.495	**0.644**	0.245
Fe^{2+}	0,201	-0.015	0.904	-0.019	**0.904**	-0.019	**0.817**	0,000
EC	0.209	-0.218	0.938	-0.280	**0.938**	-0.280	**0.880**	0.078
Cl^-	0,201	0.196	0.904	0.251	**0.904**	0.251	**0.817**	0.063
Turbidity	0.211	0.027	0.948	0.035	**0.948**	0.035	**0.899**	0.001
CSS	0.213	-0.026	0.960	-0.033	**0.960**	-0.033	**0.921**	0.001
DTS	0.199	-0.229	0.894	-0.294	**0.894**	-0.294	**0.799**	0.087
Na^+	0.204	-0.089	0.916	-0.114	**0.916**	-0.114	**0.839**	0.013
K^+	0.159	-0.033	0.715	-0.042	**0.715**	-0.042	**0.511**	0.002
Si^{4+} content	0.189	-0.242	0.852	-0.311	**0.852**	-0.311	**0.726**	0.097
Total Hg	0.200	-0.060	0.900	-0.077	**0.900**	-0.077	**0.810**	0.006
% Correlation variance	-	-	-	-	72,310	5.880	-	-

The values in bold correspond for each variable or factor for which the factor matrix or the cosine square is the largest, and / or there is a strong correlation between the variables and / or factors.

In order to elucidate the mechanisms of enrichment of the physicochemical and organic parameters in various waters of the rivers of these gold washing zones and their preferred supports of the concentration in total Hg, we carried out a principal component analysis (ACP). Thus, with regard to the information relating to the spatial dispersion of the 24 parameters measured in the waters of these nine rivers, which Table 5 highlights, it can be seen that the 2 factorial axes have a sum of explained variance percentages of almost 78, 20 % of total information with respectively 72.31% for axis 1 and 5.88% for axis 2. Therefore, the examination of the correlation matrix between the variables in the first axis, notes the presence of almost all the parameters in the positive area of axis 1 because of its strong contribution. This 1st axis is strongly correlated in a positive way with the following parameters: MS, COD,NO_3^-, NH_4^+, PO_4^{3-}, SO_4^{2-}, CO_3^{2-}, Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{2+}, CE, Cl-, Turbidity, CSS, STD, Na^+, K^+, Si^{4+} content, and total Hg. As for axis 2, it is positively and significantly correlated only with temperature. In addition, axis 1 expresses acidity, strong mineralization, chemical and mercury pollution of environmental or anthropogenic origin while axis 2 expresses biological pollution of anthropogenic origin.

CONCLUSION

The waters of nine rivers draining the gold panning sites of the Fizi territory are widely polluted by mercury and other types of pollutants; they have a very deteriorated physicochemical quality. The contents of total mercury, dissolved organic carbon, dissolved oxygen, chloride, sulphide, sulphate, suspended matter, total dissolved solids as well as the values of parameters such as pH, electrical conductivity, turbidity and the temperature deviates from the standards recommended by the World Health Organization and the Canadian Council of Ministers of the Environment. The level of pollution in the waters of these nine rivers shows the urgency of finding adequate solutions to stop it and preserve public health. To do this, training of gold panners in Fizi territory in the proper management of gold panning effluents and educate them on the use of retorts or hoods to recover mercury.

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