Use of Principal Component Analysis (PCA) for the Physico-chemical Characterization of waters of the Panda River/City of Likasi (Haut-Katanga/DRC) contaminated by mining effluents.

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Abstract: The city of Likasi is a mining center in the heart of the Katangese copper belt. Several mining companies exploit copper and/or cobalt ores in the city and discharge contaminated liquid effluents into the city's various rivers, including the Panda River and its waters, which are used for agriculture and domestic purposes and on which a water catchment dam is built for a treatment plant intended for public consumption. This river is the main tributary of the Lufira river basin (tributary of the Lualaba, name of the Congo River at its source). The Lufira is of ecological and socio-economic importance because it waters the Lufira estate, the Kundelungu and Upemba parks, which are rich in biodiversity. The pH, Conductivity and Temperature of effluents from the three mining industries (symbolized by the acronyms: MJM, CJC and BOL) at the junctions with the waters of the Panda River were measured in situ and samples collected from these three stations were assayed at the laboratory for the following seven (07) heavy metals: Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn) and Lead (Pb) using an inductively coupled plasma atomic emission spectrophotometer (ICP/OES) from PERKIN ELMER 8300 series.) The results obtained are averages of three years of sampling campaign (from 2015 to 2017) with the main objective of verifying the degree of respectability of the WHO guidelines for the discharge of mining waste water into aquatic ecosystems, but also to look for geochemical correlations, through statistical analysis, of these heavy metals discharged. The physicochemical results obtained demonstrated a low degree of respectability of WHO guidelines, especially in BOL, and statistical analyses (correlation analysis and main component analysis) identified strong correlations between different measured heavy metals, advocating common geochemical origins in the Katangese copper arc.

Keywords: Principal Component Analysis (PCA), Heavy Metals, Mining Effluents, Contamination.

1. Introduction

Industry has often favored sites near watercourses for three main reasons: transport of raw materials, water supply, which makes it possible to cool installations and discharges of industrial effluents at a lower cost. This is the reason why rivers inherit industrial discharges and industrial wastewater, liquid waste resulting from the extraction or transformation of raw materials, and all forms of production activity[1]. The contamination of river surface waters by metallic trace elements, ETM stands for ETM, is one of the major problems of this period. Trace elements are naturally present at varying concentrations in source rocks.

However, as a result of human activities, their concentrations in surface waters increase to the point of making the term "ETM" inappropriate, as they form stocks of pollutants that are potentially toxic to the environment. In addition, these stocks can evolve according to the physico-chemical conditions of the environment and largely determine their toxicity to living organisms [2],[3],[4].

Several mining industries are located in Likasi city. Most of them exploit minerals in the middle of the city and spread in all directions, so that today, these companies discharge their solid, liquid and gaseous waste into the natural environments of inhabited neighborhood's, without any prior treatment. But among these natural environments are the rivers' streams, including the Panda River, which constitute the hydrological network of the city of Likasi. This river (the Panda) has a water catchment facility for the drinking water supply of the city of Likasi and is also the main tributary of the Lufira River which waters the protected area of the Lufira and the two national parks, Kundelungu and Upemba, areas rich in biodiversity, in the former Katanga Province of the Democratic Republic of Congo (DRC). The Panda River is used as a low-cost drain for the disposal of wastewater from three industries involved in this study. These are MJM, CJC and BOL. Most of the liquid mine tailings ponds that are visible as required by mining regulations are trompe-l'oeil. During the day, these settling basins are filled with toxic liquid waste and at night, they are completely emptied into the various streams that feed the Panda River through rainwater or household drainage channels, without prior treatment. Sometimes, these settling ponds are linked with the natural environment by pipes dissipated through the subsoil. In this study, the main concern will be to address this main concern: do the mining effluents discharged into the Panda River in the city of Likasi comply with WHO guidelines? Two secondary questions are then asked in this context: is the pollution resulting from these discharges chronic or episodic? Are there significant correlations between different metallic trace elements contained in this pollutant load?This study therefore aims to assess the level of respectability of the mining regulations governing the discharge of liquid mining effluents, loaded with heavy metals, into the Panda River, and specifically, the main heavy metals responsible for mining pollution are measured in liquid effluents from the MJM, CJC and BOL industries and then geochemical correlations are determined between the various metal trace elements discharged in the effluents.

2. Study aera, Materials and Methods

2.1.Presentation of the study area

The Panda River is a watercourse in the city of Likasi, Haut-Katanga Province in the Democratic Republic of Congo. Likasi is a mining centre, an important communication node and is located in the heart of the mining region of Katanga, it is a hilly region located on the plateau of Haut-Katanga at an average altitude of 1265 m.It has about 420,000 inhabitants and belongs to the humid tropical climate. Located on 10°57'47" South latitude and 26°46'40" East longitude, the city of Likasi covers 245 km² in the mining province of Haut-Katanga, 120 km from the city of Lubumbashi, the capital of the said province in the south-east of the DRC, on the trans-African road from Johannesburg in South Africa. Its hydrological network consists mainly of the following rivers: : Buluo, Likasi and Mura which feed the Panda River. All these rivers form the Lufira catchment area, which flows northeast and feeds Lake Tshangalele 25 km away, rich in fish and crosses the Lufira Biosphere Estate, Kundelungu and Upemba National Parks.The three sampling stations constituting the three mining industries MJM, CJC and BOL were selected on the basis of their intense activity and the fact that they all discharge into the Panda River as shown in the following ***Figure 1***:

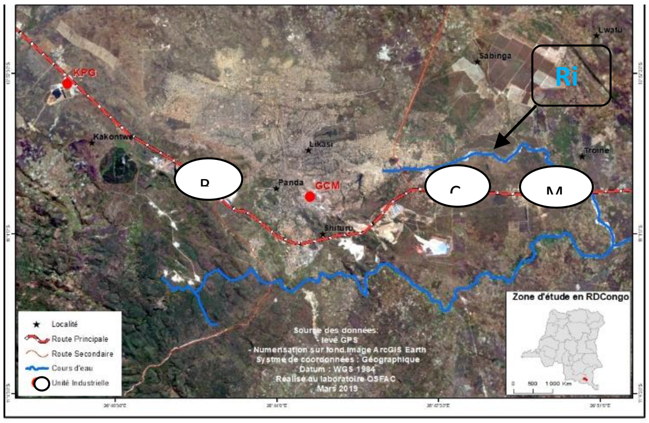

Figure 1: Presentation of the study area

2.2 Materials and methods

2.2.1. Physico-chemical analyses

pH, Conductivity and Temperature were measured in situ and seven heavy metals were measured by an inductively coupled plasma atomic emission spectrophotometer (ICP/OES) of the PERKIN ELMER series 8300) at the laboratory of the Office Congolais de Contrôle (OCC/Lubumbashi). Indeed, the location of the measurement and sampling stations was made possible thanks to a GPS map 62sc from GARMIN, but also, with the help of digital mapping carried out by the ArcGis Earth software based on geographical data from the OSFAC Laboratory; the electrical conductivity (C in µS/cm) was measured with a WTW TetraCon field conductivity meter, 1970i series, while the temperature (T°C) and pH of the water were measured respectively with a thermometer coupled to the Wagtech pH meter, EN16-102 series. The water sampling for physico-chemical analyses was carried out using the bottles half full and transferred to labelled glass bottles, which were previously rinsed with the water to be analysed. They made it possible to determine the concentrations of the following heavy metals: Arsenic, Cadmium, Chromium, Copper, Iron, Manganese and Lead.The water analysis protocols have been validated by the laboratory of the Office Congolais de Contrôle de Lubumbashi, which is in the process of being accredited.

2.2.2. Principal Component Analysis: ACP

All the data analyzed had previously been subjected to the Shapiro-Wilk (W) test to verify whether or not they follow a normal distribution. This test determined the type of analysis to be performed. In this study, Principal Component Analysis (PCA) was used to reduce the multidimensionality of data sets. It is a multivariate analysis method that allows the simultaneous study of a large number of variables whose total information cannot be visualized because of a space with more than three dimensions[5]. This method makes it possible to specify the relationships between the variables and the phenomena at the origin of these relationships[6]. It is widely used to interpret hydrochemical data[7],[8]. Results obtained in smaller dimensions simplify the interpretation of the data[2],[9]. These transformed components or independent variables are called main components (CPs). They reveal information on the most important variables explaining the data set by making the exclusion of variables considered less important, while keeping the original information with minimal loss. For this purpose, the software: XLSTAT, SPSS and SPAD were used.

3. Results and discussion

3.1. Physico-chemical analyses

The various results obtained are recorded, using statistical processing, in **Tables 1** and **2** below:

Table 1: pH, Temperature (T°C) and Conductivity (C) measurements

	MJM	CJC	BOL	Global weight edaverages	WHO
pH	**4,2**	7,1	**4,3**	**5,2**	6,5 à 9
T (°C)	26,4	25,8	26,0	26,0	≤ 30
C (µS/cm)	**6074,6**	**4278,6**	**4742,9**	**5032,03**	≤ 250

From **Table 1**, it can be seen that thermal recording is essential to understand biological, chemical and mineralogical processes. It is the result of energy and hydraulic flows at the water-atmosphere and water-bed interfaces of the watercourse. All results gave temperatures acceptable to WHO guidelines [10],[11]. With an average temperature of 26.0°C, the waters of the Likasirivers have temperatures close to those of the region's temperate tropical climate [12].

Electrical conductivity refers to the mineralization of water. The interest of Conductivity measurements is mainly manifested in their spatial evolution [6]. It was measured over three campaigns organized in 2015, 2016 and 2017. The average of 5032.03 µS/cm found on the set of 7 sampled points exceeds WHO guidelines by 20 times. These waters, because of mining activities that use concentrated sulphuric acid for metal extraction (hence low pH, i.e. very acidic), generate very strong mineralization (high conductivity).

These waters are extremely mineralized and this is chronic, given the repeatability of the results over three years of the campaign. Chronic mineralization thus reduces the quantities of fresh water in the Panda River. And therefore, those of the Lufira River, being the great receiver of these waters.

Table 2: Heavy metal content (mg/l) in water according to industrial units

Variables	Arsenic	Cadmium	Chromium	Copper	Ion	Manganese	Lead
MJM	**0,058**	**0,026**	0,037	0,223	**2,523**	**2,9**	**0,026**
CJC	**0,107**	0,003	0,006	**0,391**	1,466	**2,2**	**0,072**
BOL	**0,385**	0,002	**0,087**	**0,543**	**9,350**	**1,9**	**0,069**
Guideslines OMS	0,05	0,005	0,05	0,30	2,00	0,40	0,02

From **Table 2**, it should be noted that:

- All the waters of the Panda River are impacted by these mining activities by at least four dosed heavy metals;
- BOL comes first with 6/7 of the metals, followed by MJM and CJC with 4/7 of the heavy metals measured.

Trends by metal are illustrated in the following figures 2 to 8:

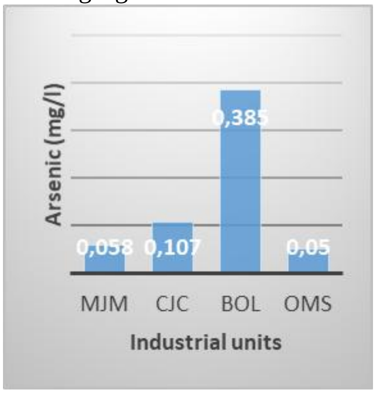

Figure 2 : Asconcentration

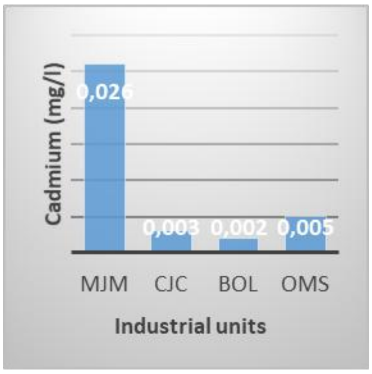

Figure 3 : Cd concentration

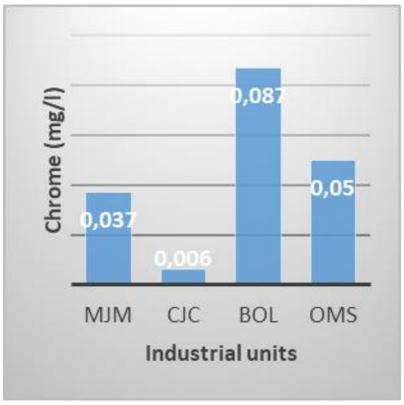

Figure 4 : Cr concentration

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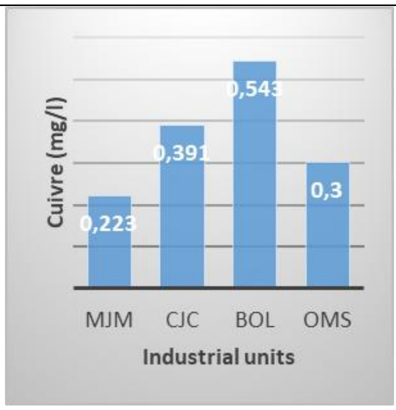

Figure 5 : Cu concentration

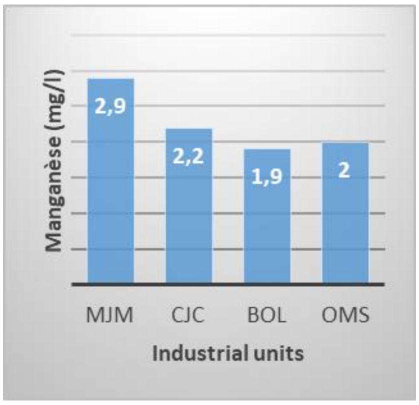

Figure 6 : Mn concentration

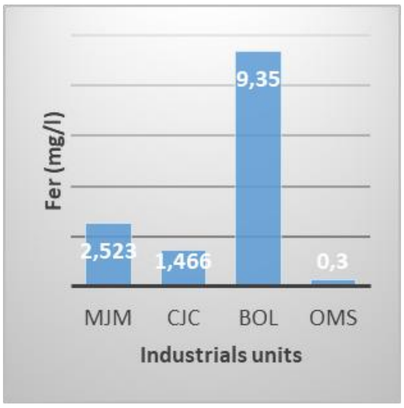

Figure 7 : Fe concentration

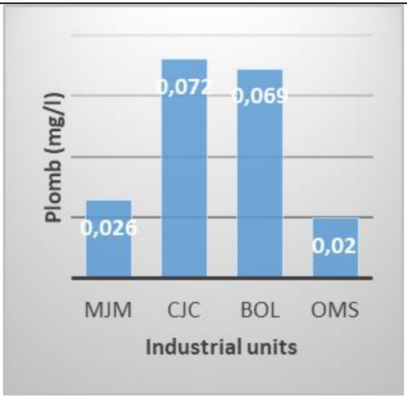

Figure 8 : Pb content

The physico-chemical laboratory results still show that the heavy metal contents studied are variable and do not have the same trends in all the selected industrial units. These heavy metals do not all present the same risks because of their effects on organisms and in the environment due to the diversity of their chemical, physico-chemical and biological properties. Although their toxicity is highly variable and their impact on the environment very different, a higher prevalence than the WHO limit[11][12] was observed over almost all the metals analysed.

It should also be noted that each heavy metal characterized the effluents as follows:
As: BOL > CJC ; **Cd** : MJM ; **Cr** : BOL; **Cu** : BOL > CJC ; **Fe** : BOL > MJM > CJC ;**Mn** : MJM > CJC > BOL.

Considering the pH and conductivity results in Table 1 on page 6, these heavy metals should be predominantly in their ionized forms. This makes the results of mineralization 20 times more plausible than the WHO guidelines and will allow this study to be taken further in determining the respective chemical speciation of each metal to better understand their toxic effects in ecosystems and alert public opinion to their health impacts.

3.2. Statistical analyses

3.2.1. Correlation analysis

The statistical analysis of the physico-chemical data was carried out on a data matrix consisting of 7 variables (dosed heavy metals and 3 sampling sites (three industries MJM, CJC and BOL) connected to streams that feed the Panda River in Likasi City. The correlation matrix and determination coefficients, respectively, given in Tables 3 and 4 below, give a first idea of the existing associations between the different heavy metals measured (As, Cd, Cr, Cu, Fe, Mn, and Pb).

Table 3: Correlation Matrix (Pearson) **:**

Variables	Arsenic	Cadmium	Chromium	Copper	Ion	Manganese	Lead
Arsenic	**1**						
Cadmium	-0,644	**1**					
Chromium	**0,864**	-0,171	**1**				
Copper	**0,916**	-0,897	0,589	**1**			
Ion	**0,966**	-0,423	**0,965**	0,780	**1**		
Manganese	-0,819	**0,966**	-0,418	-0,980	-0,641	**1**	
Lead	0,568	-0,995	0,076	**0,851**	0,335	-0,938	**1**

The different positive (green colour) and negative (red colour) correlations, obtained on the basis of the determination coefficients, are illustrated in the following ***figure 9***:

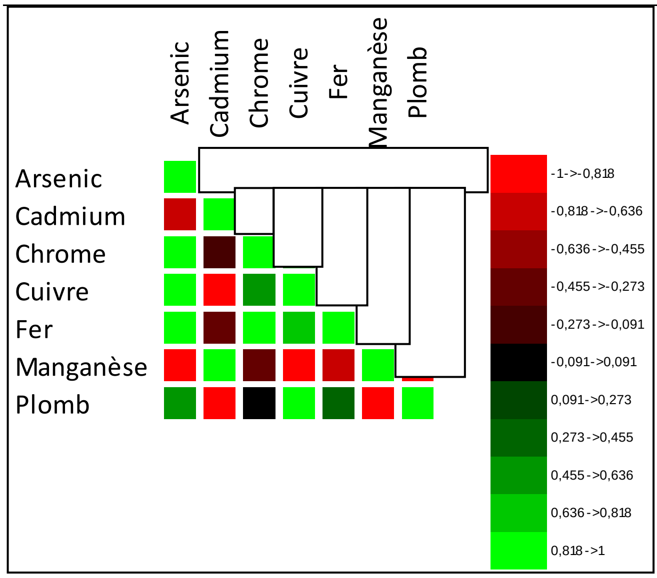

Figure 9: Different correlations illustrated in colour

These heavy metals are, for the most part, relatively correlated with each other (green colours) as follows:

- Six (06) strong positive correlations (coef. > 0.818 > 1) were observed between: As-Cr; As-Cu; As-Fe; Cd-Mn; Cr-Fe and Cu-Pb ;
- One (01) mean positive correlation (0.636 < coef. < 0.818) was observed between : Cu-Fe ;
- Two (02) low positive correlations (0.455 < coef. < 0.636) were observed between: Cr-Cu and As-Pb.
- Five (05) strong negative correlations were also observed between: As-Mn; Cd-Cr; Cd-Cu; Cd-Pb, Cu-Mn and Mn-Pb.

This will facilitate the understanding of the source of variability explained by the axes in the Principal Component Analysis (PCA).

3.2.2. Principal Component Analysis (PCA)

The following **table 4** gives the contribution of the variables in the factorial design consisting essentially of two main factors (F1 and F2):

Table 4: Eigenvalues and percentage of inertia

	Component Initial eigenvalues			Extraction Sum of the squares of the selected factors		
Component	Total	% of variance	% cumulative	Total	% of variance	% cumulative
F1	5,308	75,825	75,825	5,308	75,825	75,825
F2	1,692	24,175	100,000	1,692	24,175	100,000
F3	4,372E-16	6,246E-15	100,000			
F4	1,823E-16	2,605E-15	100,000			
F5	1,868E-17	2,668E-16	100,000			
F6	-4,942E-17	-7,060E-16	100,000			
F7	-4,570E-16	-6,528E-15	100,000			

The configuration of the eigenvalues shows that the first factorial plane, consisting of axes F1 and F2, represents 100% of the total inertia. It is sufficient to reflect the totality of this inertia. Looking at the distribution of eigenvalues, we see that the cumulative values of 100% are reached just after the first two values, which means that the first two axes (F1 and F2) are sufficient to represent the information as a whole with

75.825% of information in axis F1 and 24.175% in axis F2. The projection of all this information on the factorial plane gives the diagram of the principal components F1 and F2 in ***Figure 10***below:

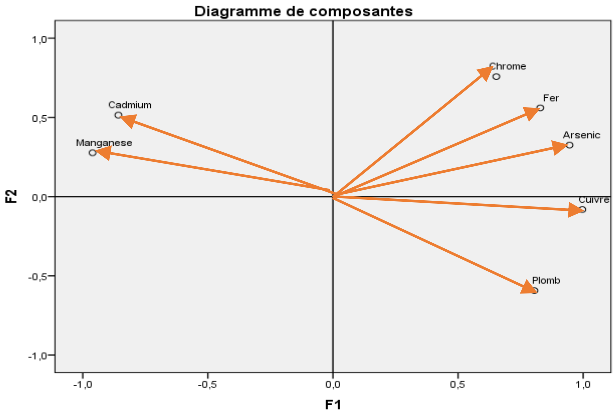

Figure 10 : Diagram of Principal Components

Figure 10 above, resulting from the factor analysis, highlights groupings, oppositions and directional trends. Cr, Fe, As, Cu and Pb have a directional tendency on the positive axis F1 which expresses 75.825% of the variance; they are the first grouping of heavy metals in the study area. The CPA confirms the trend of the six strong positive correlations obtained in the correlation analysis. This grouping contrasts with the strong positive correlation between the Cd-Mn which is observed on the positive axis F2 which expresses 24.175% of information. This statistical information confirms that all these heavy metals are of almost the same geochemical origin accompanying copper in its main minerals mined in the Likasi deposits, located in the Katangese copper arc. These statistical data thus confirm the chronic nature of pollution in the waters of the Panda River, the receiving environment for liquid mining effluents from these three mining industries (BOL, MJM and CJC).

Conclusion

The general objective of this study was to assess the level of respectability of the mining regulations governing the discharge of liquid mining effluents, loaded with heavy metals, into the receiving environment of the waters of the Panda River, one of the main tributaries of the LUFIRA. The specific objectives were to verify if all these different heavy metals have the same geochemical origin. In view of the physico-chemical results, the mining regulations relating to the discharge of mining effluents into aquatic ecosystems are not respected by these three mining industries (MJM, CJC and BOL). Heavy metal pollution of the waters of the Panda River is therefore essentially anthropogenic. The level of respectability of WHO guidelines is low. The waters are abnormally high in mineral content (20 times more than the WHO guidelines), the pH values give an average of 5.2 (compared to 6.5 to 9 for the WHO), which favours the migration of heavy metals which, in relation to this acid pH, will be in ionic form. All these industries discharge heavy metals into the water, despite the presence of settling ponds which are, in relation to these results, a trompe-l'oeil.

BOL deteriorates more than other industries and trends are presented as follows:
As: BOL > CJC > KPG ; Cd : MJM ; Cr : BOL; Cu : BOL > CJC ; Fe : BOL > MJM > CJC ; Mn : MJM > CJC > BOL ; Pb : CJC > BOL.

Chronic mineralization degrades the region's freshwater supply as this river increasingly becomes a reservoir of heavy metals that are generally toxic at high doses, due to their bioaccumulation and non-biodegradation.
Statistical analyses have established geochemical correlations between the different metals studied; they are derived from the rocks constituting the Katangese copper arc, of which the city of Likasi is a part. Copper and cobalt ores mined in the city of Likasi generally contain Iron, Manganese, Lead, Chromium, Cadmium, Arsenic, etc.Binding regulatory provisions must be put in place to stop this tragedy in Likasi.

Future prospects

The total concentration of metallic contaminants in water is not a sufficient condition to lead or not to toxic effects towards biological organisms, because this toxicity is not only related to its total concentration but also to its valence and the ligands with which it is associated. Further research is needed to identify the speciation of each metal contaminant and attempt to establish their traceability in the food chain.

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